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Crustal Dynamics Project Observing Plan for Highly Mobile Systems 1981 - 1986

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CRUSTAL DYNAMICS PROJECT OBSERVING PLAN

FOR HIGHLY MOBILE SYSTEMS

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I. INTRODUCTION

A detailed program for the measurement of crustal motion in the western United States and other tectonically active regions has been prepared for the 1983-1986 time frame which makes use of NASA's fixed, movable and highly mobile satellite laser ranging (SLR) and very long baseline interferometry (VLBI) systems. This program is a part of the overall observation program of the Crustal Dynamics Project, which includes measurement of the rotational dynamics of the Earth as well as regional deformation and plate motion.

CRUSTAL DYNAMICS PROJECT

The Crustal Dynamics Project was created by NASA to apply space technology to improving our understanding of the dynamics of the Earth. The goal of the program is to make precise geodetic measurements that satisfy the scientific objectives of improving knowledge and understanding of:

a. regional deformation and strain accumulation related to earthquakes at the plate boundary in the western United States;

b. contemporary relative plate tectonic motions of the North American, Pacific, Nazca, South American, Eurasian and Australian Plates;

c. internal deformation of continental and oceanic lithospheric plates, with particular emphasis on North America and the Pacific;

d. rotational dynamics of the Earth and its possible correlation to earthquakes, plate motion and other geophysical phenomena;

e. motions and deformation occurring in regions of high earthquake activity.

In order to meet these objectives, the Project will carry out an extensive program of repeated observations using satellite laser ranging and very long baseline interferometry techniques which have been successfully employed previously in other programs. Regular measurements of baselines between a globally distributed set of radio stations and/or laser tracking stations on different plates will provide, over time, a measurement of the relative motion of these plates. Determination of polar motion and earth rotation variations requires daily measurements from a global set of stations in stable locations. The measurement of crustal deformation and strain accumulation along active plate boundaries or in regions of high earthquake activity demands frequent high accuracy measurements between a large number of carefully chosen stations distributed throughout the region. These requirements can be met by using a combination of fixed, movable and highly mobile observing systems as described below. Project objectives will be satisfied with a measurement accuracy in the velocity (or change in baseline length) of ~ 1 cm/yr over a period of roughly five years.

AVAILABLE OBSERVING SYSTEMS

The measurements planned to meet the scientific objectives of the Crustal Dynamics Project will utilize two highly accurate observing techniques previously employed by NASA. Satellite laser ranging (SLR) measures the range to a retroreflector above the Earth's surface using very short laser pulses. High altitude satellites such as LAGEOS or the Moon are examples of targets outfitted with retroreflectors whose orbital positions are known with great accuracy. Ranging to these allows determination of the position of the laser

ranging station in an Earth center-of-mass coordinate system. Simultaneous or nearly simultaneous ranging by a pair of stations to the same satellite provides the baseline between the stations to a level of accuracy greatly surpassing conventional geodetic techniques over distances of hundreds to thousands of kilometers.

The second technique is very long baseline interferometry, in which the radio signals from very distant quasars are observed by two receiving antennas. Cross correlation of the records and calculation of the signal delay time at one station with respect to the other allows determination of the baseline between the stations in a coordinate system totally removed from the Earth. In principle, both techniques provide the relative three-dimensional position of two stations; in practice, the greatest accuracy is in the scalar baseline quantity. Repeated measurements over several years provide the velocity of one station with respect to the second (change in baseline length and direction of the change) at a level of $\sim$1 cm/yr with available instrumentation.

Both SLR and VLBI systems are available as fixed stations, movable systems and highly mobile systems. Fixed laser stations in the United States include the Goddard STALAS and the University of Texas MLRS. NASA presently has eight movable lasers (MOBLAS) deployed around the globe. These systems consist of 3-4 large vans and require extensive site preparation prior to occupation. As such they are moved only occasionally, and should be considered movable base stations rather than highly mobile, quick response systems. The first Transportable Laser Ranging System (TLRS-1) built for NASA by the University of Texas is a truck-mounted instrument capable of driving rapidly to a preselected site, occupying the site with a minimum of site preparation, and making measurements the same day.

VLBI systems suitable for the precision geodesy described here require advanced end-to-end instrumentation developed by NASA and referred to as the MARK III VLBI system. Three versions of this are to be used by the Crustal Dynamics Project. At present four fixed radio astronomy facilities in the United States have the MARK III VLBI system (Haystack Observatory, Massachusetts; Owens Valley Radio Observatory, California; National Radio Astronomy Observatory, West Virginia; Harvard Radio Astronomy Station, Texas). In the future, additional systems will be available. A second version of the MARK III VLBI system is a Transportable VLBI Data System (TVDS), where a transportable MARK III terminal is connected to an available antenna for short term measurements, thus providing a temporary fixed VLBI base station for high precision geodetic observations. Mobile VLBI systems, including the antenna, are represented by the existing ARIES systems. The ARIES 9m antenna (NASA-1) is a movable system that requires sufficiently long for set up and breakdown that it should not be moved too often. Like the MOBLAS-type SLR systems, the NASA-1 is considered a movable base station in that it may be moved to a prepared pad and operated for several months at that location. The smaller ARIES 4m antenna (NASA-2) is a highly mobile system which, like the TLRS described before, can move from one site to another in little time and which requires minimum site preparation. When equipped with the MARK III VLBI systems, the NASA-1 and 2 can be used in conjunction with a fixed station to provide triangular geometry that can rapidly change due to the high mobility of NASA-2. Thus up to 25 baselines could be measured in the course of a month between these systems. Likewise, the TLRS can move between two fixed or MOBLAS type SLR systems but, because of weather restrictions and satellite orbit ranging opportunities, probably will spend 1-4 weeks at a given site.

According to present guidelines, additional highly mobile systems will become available according to the schedule shown in Table I. A second highly mobile VLBI system, called NASA-3, will begin making field observations in the second half of 1982. Two addtional TVDS type MARK III systems will join the presently available one in 1983. In this same year, a dedicated base station system will be installed at the Goldstone tracking site in California, and will be available for limited use at other radio astronomy facilities in much the same way a TVDS is used.

In 1982 a highly mobile compact laser ranging system (TLRS-2) will begin field observations. At the beginning of 1984 two new TLRS systems (TLRS 3 and 4) will complete the list of available observing systems that can be easily deployed to a large number of sites both inside and outside the United States.

OBSERVING SITES

The availability of highly mobile SLR and VLBI systems which require in many cases no more than a bulldozed parking area means that observing sites may be chosen for these systems on the basis of scientific interest. It is possible, therefore, to obtain measurements along a major fault having a variety of baseline geometries through selection of a half-dozen locations on either side of the structure. This means that components of the motion may be more easily resolved. In addition, the likelihood of measuring small motions is also enhanced through careful selection of the observing geometry. This selection is not possible with fixed stations, which in general have been selected for their tectonic dis-interest (i.e., tectonic stability).

TABLE I. HIGHLY MOBILE SYSTEMS 1981-1986

1981	TLRS-1	NASA-2; TVDS-1
1982	TLRS-1, 2	NASA-1*, NASA-2, NASA-3; TVDS-1,
1983	TLRS-1, 2	NASA-1, NASA-2, NASA-3; TVDS-1, 2, 3
1984	TLRS-1, 2, 3, 4	NASA-1, NASA-2, NASA-3; TVDS-1, 2, 3
1985	TLRS-1, 2, 3, 4	NASA-1, NASA-2, NASA-3; TVDS-1, 2, 3
1986	TLRS-1, 2, 3, 4	NASA-1, NASA-2, NASA-3; TVDS-1, 2, 3

*THE NASA-1 IS NOT A HIGHLY MOBILE SYSTEM, BUT A MOVABLE BASE STATION USED IN CONJUNCTION WITH NASA-2 AND 3.

NOTES: TLRS-2 = CLRS (compact laser ranging system)
NASA-1 = ARIES 9m
NASA-2 = ARIES 4m
NASA-3 = ORION

It is therefore possible to consider observations in regions which otherwise could not be occupied. This has led to the recommendation by personnel within NASA, USGS, NGS, universities and other research institutions of literally hundreds of possible sites from which highly mobile systems might operate. An initial tabulation of these in 1979 (Lowman, Allenby and Frey) displayed 116 existing or proposed locations for SLR or VLBI observations. Additional recommendations have raised the total number to 216, with nearly all the additions being sites that would require highly mobile system occupations. Details concerning the selection of recommended sites, their locations, and maps displaying these locations are available in Frey, Allenby and Lowman (1980) and Lowman, Allenby and Frey (1979).

The resources available and expected to be available to the Crustal Dynamics Project do not permit occupation of and observation from all the sites recommended. A major function of the Project is to evaluate the proposed sites in terms of scientific interest, logistic difficulties and available resources and to select that subset of sites from which observations will be made. The Project is aided in this process by recommendations made by the Regional Site Selection Panel of the Interagency Coordinating Committee for Geodynamics.

Of the 216 sites so far proposed, 110 are within the North American-Caribbean part of the globe. Of these, 69 are located in the western United States and northern Mexico and are therefore directly relevant to the measurements needed to satisfy the primary science objective of the Crustal Dynamics Project. Improving the understanding of crustal deformation and

strain accumulation related to earthquakes along the plate boundary in the western United States is the highest priority goal and the one which will occupy nearly 100% of the available highly mobile systems for the next two years. In 1983 and 1984 the questions of internal plate deformation and deformation in regions of high seismic activity are addressed while measurements in California and the western United States continue.

Because of the high priority of the observations in the western United States, a brief description of the past and present measurements in this area is given below.

DEFORMATION IN THE WESTERN UNITED STATES

Movement of the Pacific plate past the North American plate produces a long region of seismic activity concentrated at and near the San Andreas fault and an area of tectonic deformation that extends eastward perhaps as far as the Rio Grande Rift. The plate boundary is wide and diffuse; the San Andreas itself is but one of a series of parallel and subparallel strike-slip faults along which various estimates of motion have been reported. To the south, rates of 5 cm/yr are reported across the Salton Trough (Savage et al., 1979). A lower rate of 3.2-3.5 cm/yr has been determined from ground surveys in central California (Mead, 1971; Savage and Buford, 1973). Near the Mexican border Gergen (1978) obtained a value of 11.1 cm/yr. The NASA sponsored SAFE (San Andreas Fault Experiment) has yielded a change in the baseline length between Otay Mt. and Quincy, California of $\sim$9.5 cm/yr determined from laser tracking data (Smith et al., 1979). The most recent observation in the SAFE Project (the fourth such measurement) produced the same value for the rate at which the baseline is decreasing in length (Smith, 1980, private communication). It is clear that measurements along the San Andreas will require numerous sites to fully resolve the deformation occurring along strike and at distances away from the fault.

Likewise detailed broadscale measurements eastward from the San Andreas Fault system will be needed to determine how the plate motion couples into deformation of the near-margin plate interior. The broad region of block faulting and high heat flow and seismic activity which characterizes the Basin and Range may have been undergoing slow extension at a rate of 0.3-1.5 cm/yr for the last several million years (Stewart, 1971). Coast-to-coast VLBI observations indicate no change in the baseline lengths between Owens Valley Radio Observatory in California and the Haystack Observatory in Massachusetts at the level of 1 cm/yr, over the last six years (Allenby, 1979; Ryan, 1980, private communication). Crustal dyanmics measurements over the next six years will provide a time base long enough to place, at the very least, upper limits on the deformation occurring in this part of the North American plate.

How the spreading of the East Pacific Rise transforms into the strike-slip plate motion along the San Andreas Fault is a related scientific problem that can also be addressed. The slow growth of the Gulf of California over the last 4 million years, at the rate of some 6 cm/yr, occurs through right-lateral strike-slip faulting along large en echelon transform faults that change through the Salton Trough int   ie San Andreas system. Atwater (1970) has suggested that some of this motion in the Gulf of California is translated into the Basin and Range. Clearly SLR or VLBI measurements along the Gulf of California are also necessary to fully resolve the picture of crustal deformation in the western United States.

DEFORMATION IN REGIONS OF HIGH EARTHQUAKE ACTIVITY

Highly mobile SLR and VLBI systems can contribute to plate motion and intraplate deformation studies by providing occupations at sites that complement the existing fixed stations. They are especially important in studying regions of high seismic activity associated with plate boundaries. Three high priority areas scheduled for occupation by TLRS and/or ARIES type systems are Alaska, the Caribbean and the west coast of South America.

The high seismic activity and the presence of significant seismic gaps make Alaska a prime candidate for space geodetic studies. The complex arrangement of faults along the curving plate boundary will make selection of sites difficult, but sufficient three system geometry should be available to place limits on the crustal deformation occurring in this area.

The Caribbean is a small but very complex plate. Within the lifetime of the Crustal Dynamics Project only reconnaissance-type studies are possible, but baselines between sites inside and outside the plate should provide a first order picture of the movements which can later be studied with a selected high density distribution of observing sites.

Convergence between the Nazca and South American plates along the west coast of the continent can be measured from Easter Island by selecting at least three sites inland from the subduction zone. Much more can be learned about the distribution of strain along the convergent boundary by selecting several pairs of sites--one on the coast, one further inland--running down the coast along the curving plate margin. These observations are of high priority because of the severe earthquake hazard in this part of the world.

II. THE HIGHLY MOBILE SYSTEM OBSERVING PROGRAM

OVERVIEW AND CONSTRAINTS

Beginning in 1981 the Crustal Dynamics Project will make repetitive measurements in the western United States and elsewhere to determine the motions and deformations associated with plate motion, intra-plate deformation and plate margin processes. The measurements required to satisfy the objectives of the Project can only be made by the deployment of highly mobile systems to complement the existing distribution of fixed VLBI and SLR stations.

Numerous constraints limit the operation of the highly mobile systems. These limitations in turn restrict the number and timing of the observations, and therefore the approach taken to meet Project goals. The basic assumptions that go into this observing program are:

a. The number of highly mobile systems available increases during the Project lifetime as shown in Table I.

b. A dedicated MARK III VLBI base station system becomes available in 1983, which can be moved like a TVDS but which generally resides at Goldstone, CA.

c. A TLRS-type system requires ~1 month on each site to overcome weather and satellite pass geometry problems in securing enough data.

d. A NASA-2 or 3 type system can in principle make two site visits per week up to ~30 sites per year (based on an estimate of base station time likely to be available to support the mobile VLBI program).

Additional basic constraints include the following:

1. Once a site is visited, it is revisited the next year, every year, by the same type of system.

2. No new sites are added after 1984 (1985, 1986 are carbon copies of 1984, in order to have a minimum 3-year time base of observations).

3. The TLRS-2 spends all of 1982 in Easter Island; thereafter the CLRS spends 6-months in Easter and 6-months in the western United States.

4. Roughly 10% of the observing sites (including fixed system location) are to be occupied by both kinds of systems.

The last constraint provides a necessary and very important check on the systems throughout the lifetime of the Project. Identical baselines will be measured by both SLR and VLBI techniques which will constitute a continuous intercomparison of the systems. For example, the NASA-2 system will visit the SLR base station on Monument Pk. (see below), as well as the TLRS sites at Yuma, Flagstaff and Vernal. Likewise the TLRS will occupy the NASA-1 site at Vandenberg and the VLBI base stations at Goldstone and OVRO. Boulder and Ft. Davis are both SLR and VLBI base stations, and Quincy (an SLR base station) is located near the VLBI base site at Hat Creek.

A division of responsibility has been made, based on considerations of weather, the existing distribution of SLR and VLBI fixed systems, the expected deployment of MOBLAS systems for the next several years, and the numerical imbalance in sites occupied per year by the highly mobile SLR and VLBI systems. The VLBI NASA 1-3 systems will have prime responsibility for California, the northern part of the western United States, Alaska, central and eastern United States, and the Caribbean. Primary observations in the southern part of the western United States, in Mexico and Baja California, along the western coast of South America and on the Nazca plate will be made by the TLRS type systems. There have been planned sufficient mutual occupations of sites by both systems to insure not only a system intercomparison but also overlap of the areas of operation so a complete picture of crustal deformation can be realized.

SLR, VLBI BASE STATIONS

Although the measurement of crustal deformation and strain accumulation in the western United States and elsewhere depends heavily on the highly mobile systems, these in turn depend on the existence of fixed base stations with which to simultaneously observe either satellites or quasars. SLR base stations are necessary for maintaining accuracy in the satellite orbit through which the position of the highly mobile system is determined. For VLBI observations the large fixed antennas provide the necessary sensitivity for observing the distant quasars, against which the lower signal/noise of the highly mobile system data can be correlated.

For the time period 1981-1986 the only fixed, non-movable laser base stations in the United States are those at GSFC (STALAS) in Greenbelt, MD (#39) and the MacDonald Laser Ranging System (MLRS) at Ft. Davis, TX (#33). Other SLR base stations necessary to support the TLRS observing program in the western United States are provided by the long term occupation of selected sites by MOBLAS systems. Throughout the last eight years, MOBLAS systems have been repeatedly located at Otay Mt. (#1) and Quincy (#14) in California as part of the SAFE Project. Because it is highly desirable to continue building on the existing history of observations, it was decided early that these same two sites would be permanently occupied during the 1981-1986 life time of the Crustal Dynamics Project.

However, the Quincy (#14) site must be vacated for ~3-months during the summer fire season, as the MOBLAS is located on a helicopter pad used in fire fighting. This requires scheduling the highly mobile TLRS into areas near other base stations during this time. Furthermore, it has become necessary to

abandon Otay Mt. (#1) as a permanent site due to safety problems associated with repeated washout of the access road. A new site, located slightly to the northeast, has been located at Monument Pk. (#701), which will become the permanent southern California SLR base station through MOBLAS occupation. A reoccupation of Otay Mt. (#1) by a MOBLAS system which Monument Pk. (#701) is likewise occupied is part of an extensive campaign to geodetically tie the two sites together in order to recover the past history of the Otay-Quincy measurement.

A fourth SLR MOBLAS base station will be located near Boulder, CO (#24) to provide support for the TLRS observations in the western United States. The three MOBLAS and one fixed SLR station (in Texas) provide solid observing geometry for accurate determination of the LAGEOS orbit and determination of the highly mobile system position.

TLRS observations in Mexico and Baja California, planned to begin in 1982, require a base station to be located near Mazatlan, Mexico (#71). This will be occupied by a MOBLAS system.

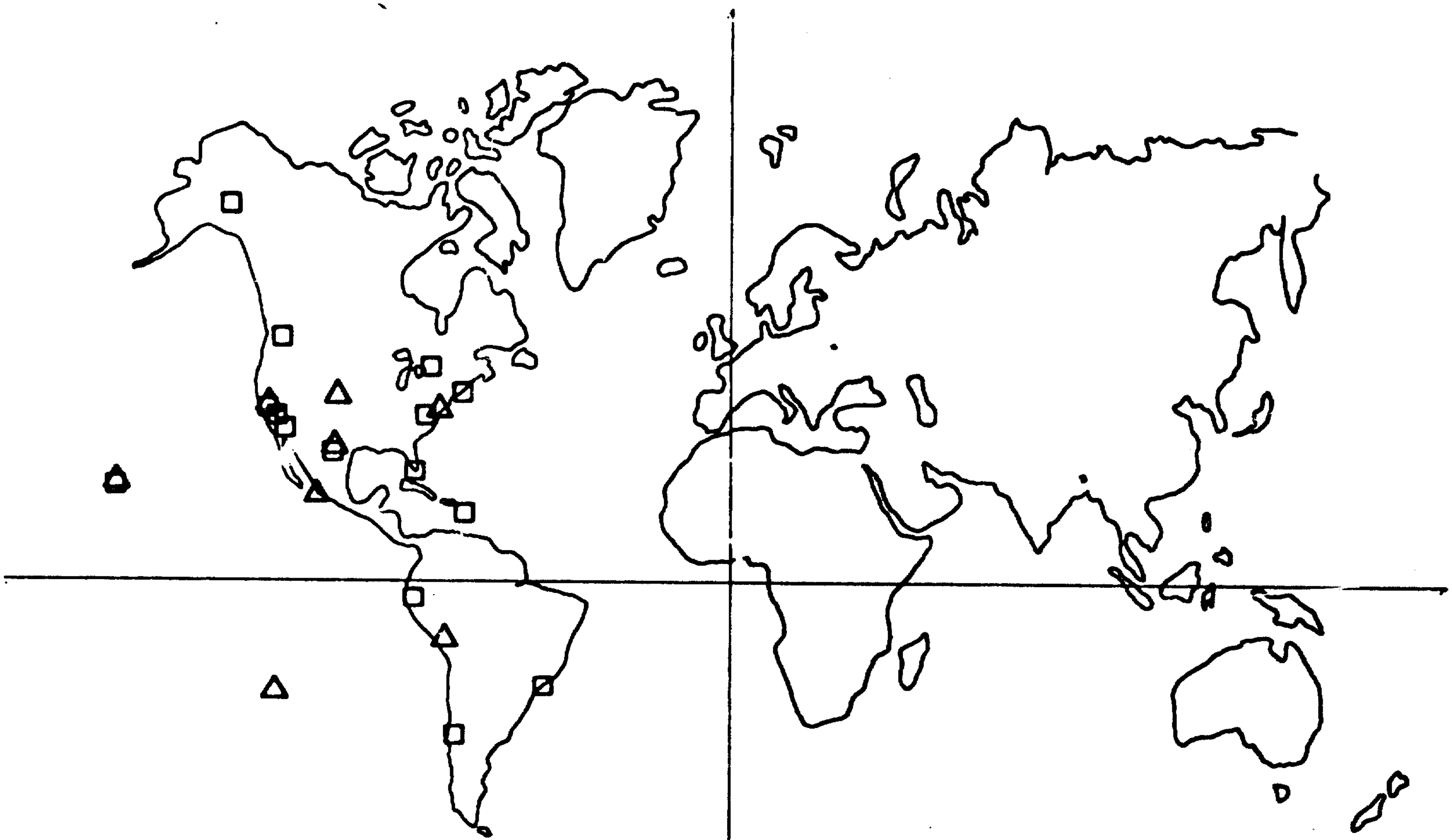
South American observations will take advantage of the base station at Arequippa, Peru (#98). Originally an SAO laser site, it is planned to upgrade this system through installation of a MOBLAS at the South American site. Locating the CLRS on Easter Island (#96) provides another temporary base station there against which a TLRS can work while observing from the South American coast. A fixed system in Hawaii (#90) called HOLLAS provides ties to the Pacific plate for the CLRS.

The fixed VLBI base stations in the United States are located at Owens Valley Radio Observatory (OVRO) in California (#11), Ft. Davis TX (#33), the National Radio Astronomy Observatory (NRAO) in West Virginia (#38), and at the Haystack Observatory in Massachusetts (#41). In 1983 a new fixed VLBI base station at Richmond, FL is expected to come on line. This distribution of fixed systems will be complimented by using the TVDS (or dedicated base station system) at Goldstone and Hat Creek, CA (#8, #14 respectively), Fairbanks, Alaska (#61), Penticton and Algonquin Observations in Canada (#69 and #67) and at the Danville facility in Illinois (#37). For highly mobile VLBI observations in the Caribbean, a TVDS will be sent to Areceibo, Puerto Rico (#77) and Quito, Ecuador (#94). Location of two additional TVDS facilities in South America at Santiago, Chile (#99) and Sao Paulo, Brazil (#102) provides the minimum geometry for intraplate deformation studies.

It is also planned to send a TVDS to Hawaii (#90) and Kwajalein (#136) at the time the Fairbanks, AL (#61) dish is occupied by TVDS to establish a plate motion measurement configuration between the Pacific and North American and between the Pacific and Asia. This program is targeted for 1983 to coincide in part with the expected completion of a Japanese VLBI facility at Kashima (#138).

Figure 1a shows the global distribution of VLBI and SLR base stations which support the highly mobile systems. Other fixed systems not generally used in the highly mobile program are not shown, despite their importance for the plate motion studies in the Crustal Dynamics Project. An enlargement of the region including North America and the Caribbean is shown in Figure 1b, which represents the area in which more than 60% of the highly mobile system observations will be made.

SLR, VLBI BASE STATIONS FOR HIGHLY MOBILE SYSTEMS



△ LASER BASE STATION

□ VLBI BASE STATION

FIGURE IA

NORTH AMERICAN SLR, VLBI BASE STATIONS FOR HIGHLY MOBILE SYSTEMS

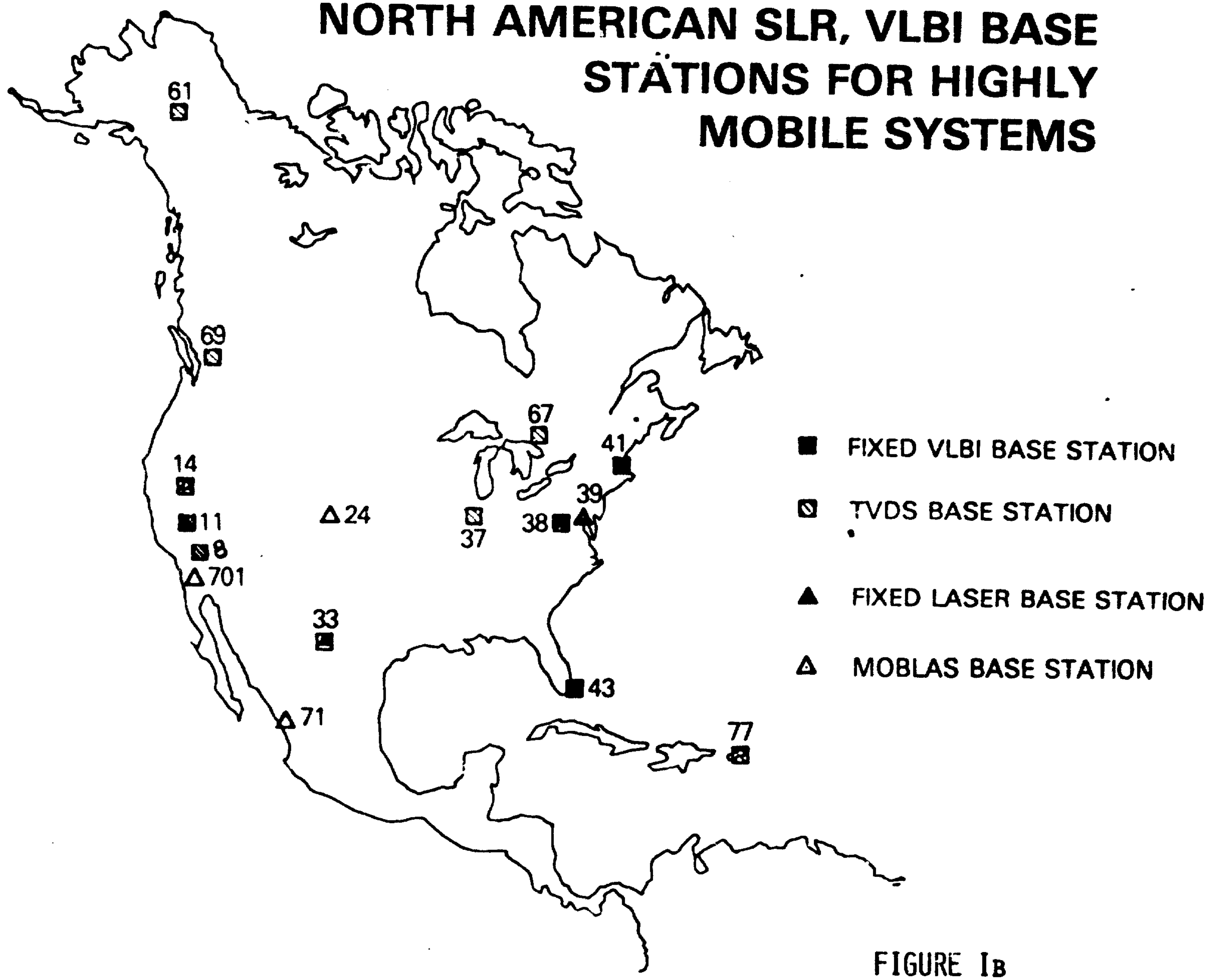


FIGURE IB

DESCRIPTION OF THE OBSERVING PROGRAM

The deployment of the highly mobile systems is shown as a series of Tables, one for each of the years 1981-1984. The 1985, 1986 observing program is identical to that for 1984. Each year is divided into the VLBI and SLR systems. Each Table shows the location of systems during each of four weeks of each month. By assuming each month has only four weeks we have ignored four additional weeks each year, which time will undoubtedly be needed for system refurbishment and relocation above and beyond that already built into the program. In addition to showing the deployment of the highly mobile systems, we also indicate the required base station support.

The Tables are accompanied by a series of maps to show the site locations. For simplicity and because the details are on firmer ground, the observing program for 1981 and 1982 is described in detail. The program for 1983 and 1984-86 is also shown in Tables IV-V, but details are only briefly described in the text. It is expected that results from the 1981-1982 program may necessitate some changes in the following years.

III. THE 1981 OBSERVING PROGRAM

SLR (TLRS)

The 1981 highly mobile SLR program is confined to the western United States and California, and is shown in Table IIa and Figure 2a. The quadrilateral formed by the four SLR base stations at Monument Pk. (#701), Quincy (#14), Boulder (#24) and Ft. Davis (#33) provides by itself a strong series of baselines crossing the Basin and Range and connecting California with the presumably stable interior of the North American plate. Monument Pk. is on the Pacific Plate, and the Monument Pk.-Quincy baseline should measure the relative motion of the Pacific-North American Plates. The sites selected for occupation by the TLRS were chosen to further define this motion and to provide measurements related to the coupling of this motion into the tectonic deformation of the western United States.

Engineering considerations and colocation tests with the NASA-2 at JPL will delay the operational phase of TLRS observations until March. From March through June the TLRS will visit, in order, Vandenberg AFB (#9), Yuma (#202), Goldstone (#8) and OVRO (#11). The Vandenberg site provides an additional baseline to Quincy (#14) across the San Andreas Fault, thereby measuring plate motion, and the Vandenberg-Monument Pk. (#701) baseline can monitor the stability of the continental sliver of California which makes up the extreme eastern edge of the Pacific Plate. Baselines from Yuma to Monument Pk. cross the complicated Salton Trough area where the San Andreas Fault system splits southern California into numerous separate blocks. Also, the Yuma-Ft. Davis (#33) line and Yuma-Boulder (#24) line both cross the Basin and Range, providing measurements of the possible extension occurring in two different regions.

TABLE IIa. 1981 HIGHLY MOBILE SLR OBSERVING PROGRAM
(See Figure 2a)

	TLRS-1	TLRS-2	TLRS-3	TLRS-4	SUPPORTING BASE STATIONS
JANUARY		N/A	N/A	N/A	
FEBRUARY					
MARCH	Vandenberg (9)				
APRIL	Yuma (202)				Monument Pk. (201)*
MAY	Goldstone (8)				Quincy (14)* Boulder (24)*
JUNE	OVRO (11)				Ft. Davis (33)
JULY		V	V	V	

NOTE: * = MOBLAS

TABLE IIa. (continued)

	TLRS-1	TLRS-2	TLRS-3	TLRS-4	SUPPORTING BASE STATIONS
AUGUST		N/A	N/A	N/A	
SEPTEMBER	Bear Lake (22)				Otay Mt. (1)*
OCTOBER	Trinidad (31)				Monument Pk. (201)* Quincy (14)*
NOVEMBER	Vernal (413)				Boulder (24)* Ft. Davis (33)
DECEMBER	Flagstaff (27)				

1981 SLR HIGHLY MOBILE SITES

MARCH - JUNE, SEPTEMBER - DECEMBER

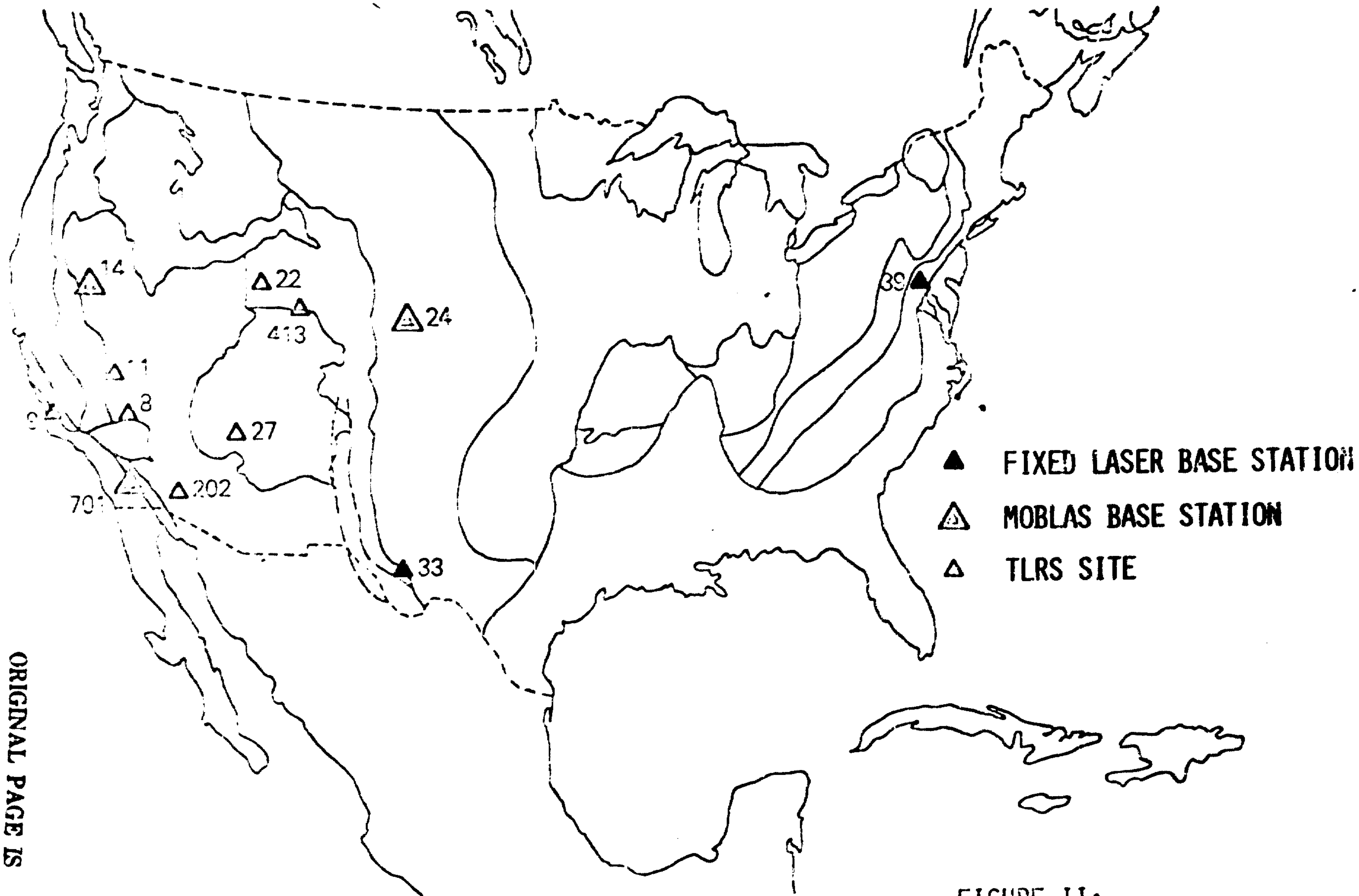


FIGURE IIA

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Location of the TLRS at the VLBI base stations at Goldstone and OVRO directly complements observations by VLBI systems when the ARIES 4m visits Monument Pk. (#701), as described below. The Monument Pk.-OVRO and Monument Pk.-Goldstone baselines will therefore by measured by both types of systems, tying the SLR and VLBI base stations together repeatedly during the 1981-1986 time period.

July and August are scheduled as down time for the TLRS, during which time it will return to Ft. Davis for system upgrade and refurbishment. This corresponds to a part of the time the Quincy (#14) MOBLAS base station is unavailable.

From September through December the TLRS will visit a maximum of four sites in the western United States: Bear Lake (#22--if the Quincy base station is back on the air), Trinidad (#31), Vernal (#413) and Flagstaff (#27). These sites provide ties across the Basin and Range to the presumably stable Colorado Plateau and the plate interior. The Trinidad (#31) occupation is a first epoch measurement for a later pair of sites which will measure possible extension in the Rio Grande Rift. Likewise the Flagstaff-Boulder (#27-#24) and Flagstaff-Ft. Davis (#27-#33) occupations also provide information on whatever extension may be occurring in the Rift. The Bear Lake site was previously occupied by a MOBLAS system in 1976 and again in 1979 as part of the SAFE Project.

VLBI (NASA-2; TVDS 1)

The 1981 highly mobile VLBI observing program lacks the advantage of the NASA-1 movable base station. OVRO (#11) and Ft. Davis (#33) are fixed stations, and the TVDS-augmented antennas at Goldstone (#8) and Hat Creek (#14) provide additional base stations in California. However, only a single TVDS is available in 1981, so it must be moved from Goldstone to Hat Creek in August, as shown in the schedule in Table IIb. Figures 2b and 2c show the locations of NASA-2 sites for 1981, which have been arranged as four groups of 4-5 sites each. These are described below.

a. February 1981: The NASA-2 will move from JPL (#6) to La Jolla (#2), Palos Verdes (#4), Vandenberg AFB (#9), Pearblossom (#7) and back to JPL. The La Jolla-OVRO baseline crosses the central San Andreas Fault with reasonably good geometry for contributing to the measumrement of plate motion, and repeats a measurement made in 1977. The Pearblossom and JPL to Goldstone and OVRO baselines continue a history of observations in an active tectonic region in which movement has been reported. The Palos Verdes and Vandenberg sites expand the scope of these same measurements in an attempt to determine how extensive crustal deformation may be south and west of the San Gabriel Fault. Also, Vandenberg is scheduled to be occupied in 1982 by the NASA-1, so the 1981 visit by the NASA-2 provides a first opoch measurement of this site location with respect to OVRO and Goldstone.

b. May 1981: Five sites in southern California are scheduled for NASA-2 occupation. Pinon Flats (#204) in the Salton Trough will be a NASA-1 location in 1982, from which the deformation in this region will be studied. The Yuma (#202) site was also selected to study the crustal motions in the Salton Trough region, and is a location which will also be occupied by TLRS. Moving the NASA-2 to Monument Pk. (#701), the SLR base station in southern California, provides

TABLE IIb. 1981 HIGHLY MOBILE VLBI OBSERVING PROGRAM
(See Figure 2b,c)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING BASE STATIONS
JANUARY	N/A		N/A		N/A	N/A	
FEBRUARY		LaJolla (2) Palos Verdes (4) Vandenberg (9) Pearblossom (7) JPL (6)		Goldstone (8)			OVRO (11)
MARCH							
APRIL							
MAY		Pinyon Flats (204) Yuma (201) Monument Pk. (701) Santa Paula (405) JPL (6)		Goldstone (8)			OVRO (11)

TABLE IIb. (continued)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING BASE STATIONS
JUNE	N/A		N/A		N/A	N/A	
JULY		Pearblossom (7) Gorman (207) Anderson Pk. (12) Pt. Reyes (212) Presidio (13)		Goldstone (8)			OVRO (11)
AUGUST				Hat Creek (14)			
SEPTEMBER		Flagstaff (27) Vernal (413) Boulder (24)					OVRO (11) Ft. Davis (33)
OCTOBER		Duckwater ([illegible])					

TABLE 11b. (continued)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING BASE STATIONS
NOVEMBER	N/A		N/A		N/A	N/A	
DECEMBER							

1981 VLBI HIGHLY MOBILE SITES

FEBRUARY, MAY, JULY

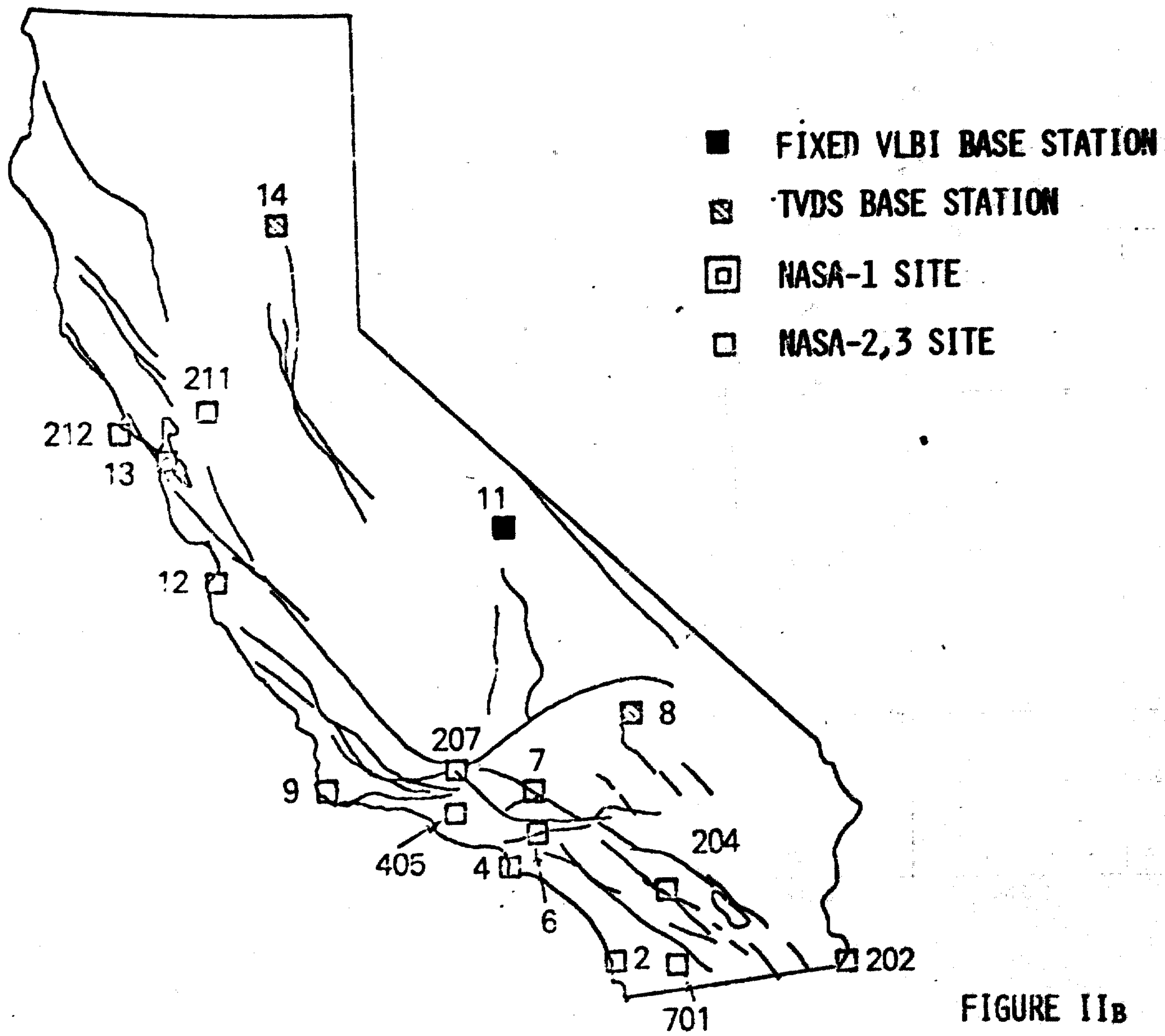


FIGURE IIB

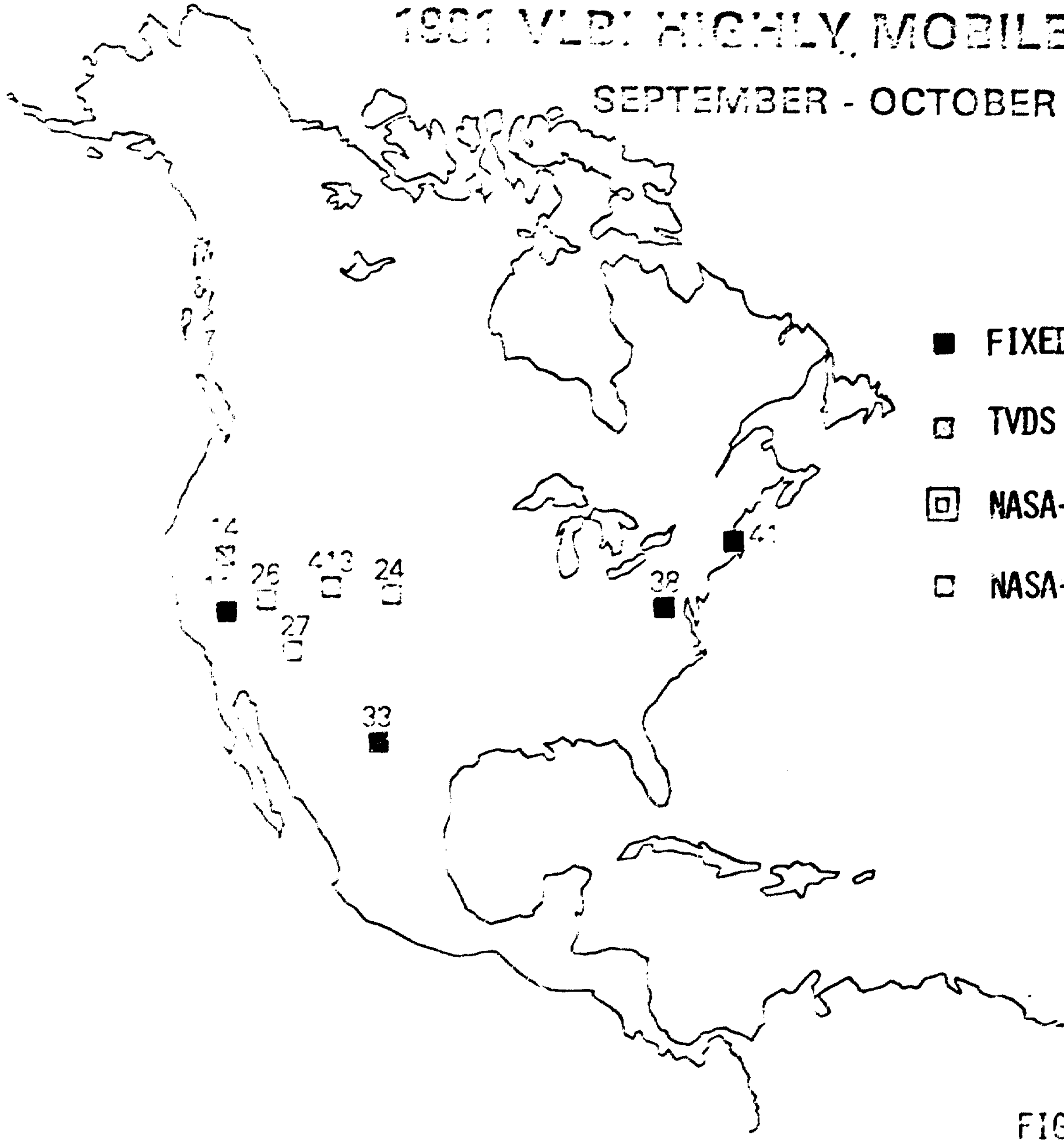
baselines identical to those obtained by the SLR technique when the TLRS visits Goldstone (#8) and OVRO (#11). This is part of a continuing intercomparison of the two techniques which also ties together the base stations for VLBI and SLR in southern California. Santa Paula (#405) in the Transverse Ranges complements the earlier measurements from Vandenberg (#9) described above. The final observation in this series is a reoccupation of JPL (#6).

c. July 1981: This third leg of the 1981 mobile VLBI observing program concentrates on sites in central California where baselines to the OVRO and Goldstone base stations cross the San Andreas at a variety of locations. A reoccupation of Pearblossom (#7) is followed by observations from Gorman (#207), at the intersection of the San Andreas, Big Pine, Garlock and San Gabriel Faults. Anderson Pk. (#12) will become an ARIES 9m base station location in 1982; the line from here to Goldstone crosses the San Andreas Fault such that plate motion should produce an increase in baseline length over time. The same is true for the baseline from Pt. Reyes (#212), located west of the San Andreas Fault, just north of San Francisco. A point on the eastern side of the Fault near San Francisco, at Presidio (#13) is the final site to be visited in California in 1981.

d. September 1981: Following the move of the TVDS 1 from Goldstone to the northern California base station at Hat Creek (#14) in August, the NASA-2 will travel into the western United States and observe from four sites: Flagstaff (#27), Vernal (#413), Boulder #24) and Duckwater/Ely (#26). Both Flagstaff and Vernal are on the Colorado Plateau; baselines from here to OVRO (#11) and Hat Creek (#14) cross the Basin and Range at enough different places to give a good picture of the possible E-W extension that may be

1981 VLBI HIGHLY MOBILE SITES

SEPTEMBER - OCTOBER



■ FIXED VLBI BASE STATION

▫ TVDS BASE STATION

⊡ NASA-1 SITE

□ NASA-2,3 SITE

FIGURE IIc

occurring there, after several years of observation. Boulder (#24) will be a NASA-1 base station in 1982 and provides a tie across the entire western United States into the stable interior of the North American Plate. The Duckwater/Ely (#26) site was chosen to provide an intermediate point for baselines across the northern Basin and Range to help resolve whatever motion may be occurring there.

IV. THE 1982 OBSERVING PROGRAM

The major thrust of the 1982 highly mobile observing program is two-fold: (a) reoccupation of already visited sites, and (b) occupation of selected new sites to expand the observing network. The first is required to provide the first epoch velocity measurement. Expansion of the network is necessary to provide a complete picture of the deformation occurring along the San Andreas and in the western United States, and to begin study of deformation in other regions of high seismic activity. TLRS observations in 1982 will occur from 11 sites, an increase of three locations. In addition, the newly completed TLRS-2 will be available, but for 1982 this system will be located on Easter Island (#96), as described below. The highly mobile VLBI program will be greatly improved by the availability of the NASA-1. This movable base station will make possible the selection of particularly interesting baseline geometries, and in general the NASA-2 observations are closely tied to the NASA-1 location. In addition, a second highly mobile VLBI system, NASA-3, becomes field operational in the second half of 1982. This means the NASA-2 and 3 can work in combination around the NASA-1, further increasing the ability to select significant baselines for direct observation. The SLR observing program is shown in Table IIIa for 1982, and in Figures 3a and 3b. The 1982 observing program for VLBI is shown in Table IIIb and Figures 3c-f.

SLR (TLRS-1, 2)

The TLRS-2 under development at the Goddard Space Flight Center will be deployed to Easter Island (#96) for 1982. From there it will range to provide

TABLE IIIa. 1982 HIGHLY MOBILE SLR OBSERVING PROGRAM
(See Figures 3a,b)

	TLRS-1	TLRS-2	TLRS-3	TLRS-4	SUPPORTING BASE STATIONS
JANUARY	Goldstone (8)	Easter Is. (96)	N/A	N/A	
FEBRUARY	OVRO (11)				Monument Pk. (701)* Quincy (14)*
MARCH	Vandenberg (9)				Boulder (24)* Ft. Davis (33)
APRIL	Yuma (202)				
MAY	Santa Rosalia (218)				Monument Pk. (701)* Ft. Davis (33)
JUNE	San Felipe (219)				Mazatlan (71)*
JULY					

NOTE: * = MOBLAS

TABLE IIIa. (continued)

	TLRS-1	TLRS-2	TLRS-3	TLRS-4	SUPPORTING BASE STATIONS
AUGUST	Talara (340)		N/A	N/A	Hawaii (90) Easter Is. (96)
SEPTEMBER	Santiago (99)				Arequippa (98)*
OCTOBER	Trinidad (31)				Monument Pk. (701)*
NOVEMBER	Vernal (413)				Quincy (14)* Boulder (24)*
DECEMBER	Flagstaff (27)				Ft. Davis (33)

baselines to Hawaii (#90) and Tahiti (#92) on the Pacific Plate. This should provide a rapid test of plate tectonic theory in the region of rapid spreading along the East Pacific Rise. The TLRS-2 will also contribute to the measurement of convergence between the Nazca and South American plates through observations with the MOBLAS base station at Arequippa, Peru (#98). These two sites are base stations for two South American sites scheduled for TLRS-1 occupation (see below).

Repeat occupations of Goldstone (#8), OVRO (#11), Vandenberg (#9) and Yuma (#202) are first on the 1982 TLRS observing program. These reobserved baselines provide the first epoch velocity measurements between these sites and the Monument Pk. (#701), Quincy (#14), Boulder (#24) and Ft. Davis (#33) base stations. The Vandenberg-Quincy line is particularly interesting in that it complements the Monument-Quincy measurement.

A major innovation in the TLRS observing program is the scheduled occupation of two sites in Baja California and two sites in South America. Extension of the measurements through southernmost California into the Gulf of California is necessary to determine how the plate motion changes from spreading in the south to strike-slip displacement to the north. A MOBLAS base station will be located at Mazatlan (#71), on the western coast of Mexico, on the east side of the Gulf of Mexico. TLRS-1 will visit two sites, Santa Rosalia (#219) and San Felipe (#218) on the western side of the Gulf. Baselines from here to Mazatlan (#71) cross the Gulf with good geometry parallel to the transform motion which occurs there. Furthermore, the Mazatlan-Monument Pk. (#71-#70) baseline will be repeatedly measured to determine the gross plate motion occurring near the Mexican border. These sites are shown in Figure 3a.

1982 SLR HIGHLY MOBILE SITES
JANUARY - JUNE, OCTOBER - DECEMBER

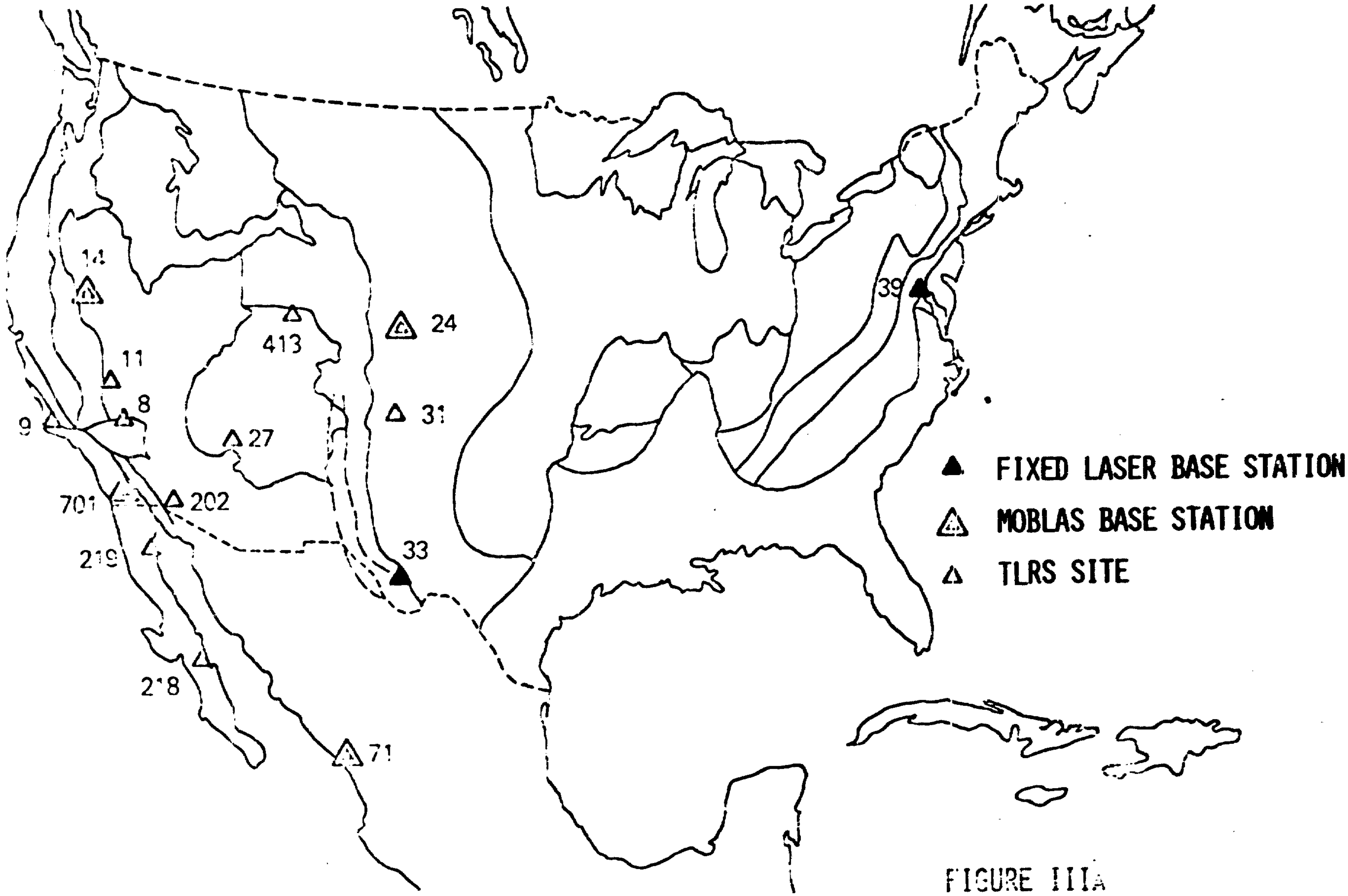


FIGURE IIIA

1982 SLR HIGHLY MOBILE SITES
AUGUST - SEPTEMBER

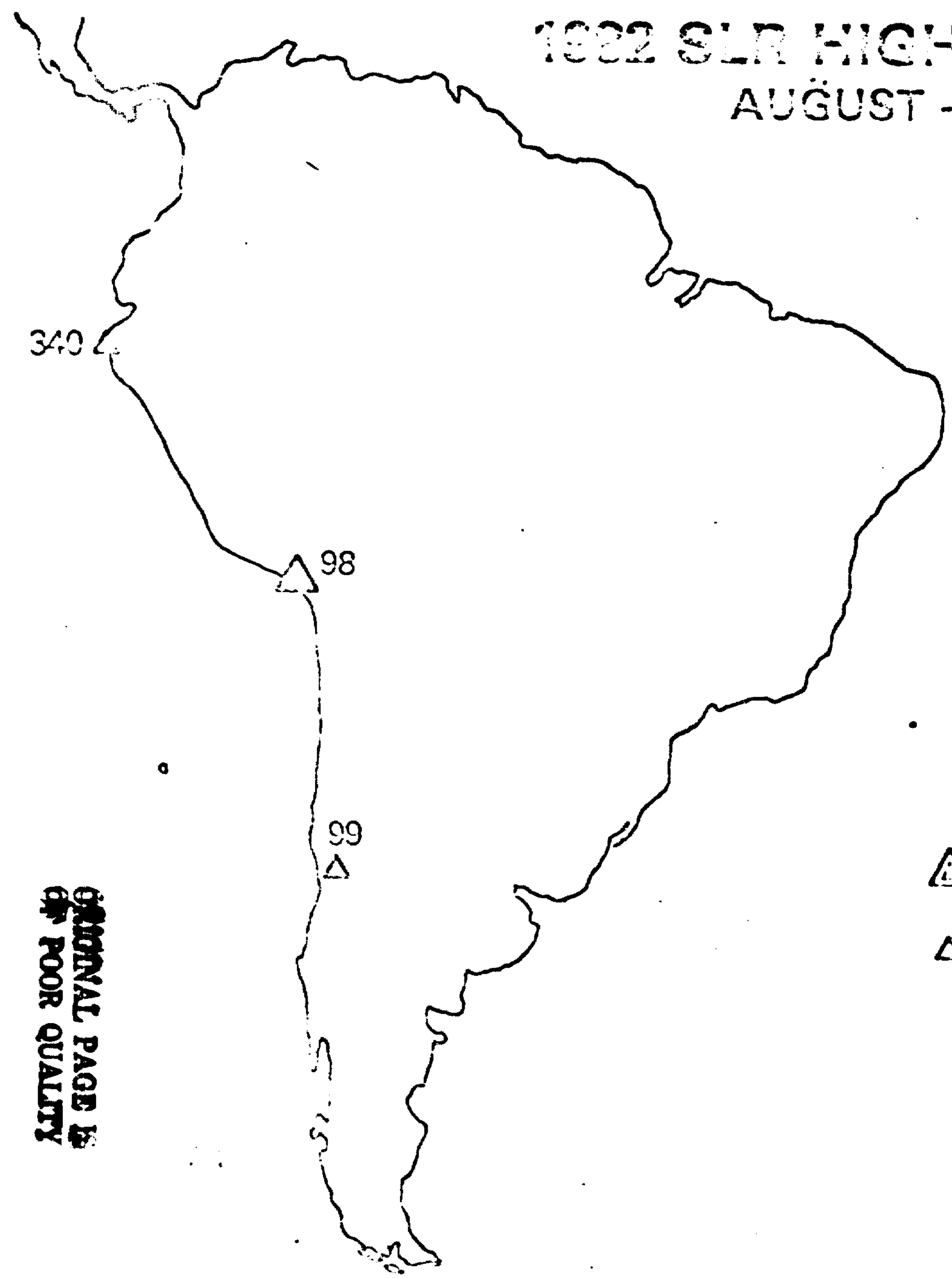


FIGURE IIIB

Following the two Baja California observations, a month has been set aside for system preparation and transportation to South America. Two widely separated sites are scheduled for occupation in August and September of 1982. Talara (#340) is north of the Arequippa (#98) base station, Santiago (#99) is to the south. Baselines from Easter to these sites measure the rate of plate convergence along the Peru-Chile Trench (see Figure 3b).

From Santiago (#99) TLRS-1 will be air-transported back to the United States where it will reoccupy three western sites: Trinidad (#31), Vernal (#413) and Flagstaff (#27).

Not shown in Table IIIa is an expected brief occupation of Mt. Wilson (#407) for horizontal ranging observations to tie together NGS ground survey networks. Tentative plans call for ~ 3-4 day visit to Mt. Wilson between the Vandenberg (#9) and Yuma (#202) occupations, in late March.

<u>VLBI (NASA-1, 2, 3; TVDS-1)</u>

The schedule for the highly mobile NASA-2 and 3 systems is closely tied to the site location of the NASA-1. Four observing periods have been scheduled in 1982, as shown in Table IIIb. Figures 3c-f show the location of the sites occupied. The single TVDS is moved from the Goldstone base station to Hat Creek in the middle of the third session, necessitating 1 week of no observations at the end of July. The NASA-3 highly mobile system is expected to become available about June, and observations after this are planned as paired occupations by the NASA-2 and 3.

TABLE IIIb. 1982 HIGHLY MOBILE VLBI OBSERVING PROGRAM
(See Figures 3c-f)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING BASE STATIONS
JANUARY			N/A		N/A	N/A	
FEBRUARY	Pinyon Flats (204)	Yuma (202) Signal Mt. (201) Monument Pk. (7[illegible]) Palos Verdes (4) Santa Paula (40[illegible]) JPL (6)		Goldstone (8)			OVRO (11) Ft. Davis (33)
MARCH							
APRIL	Anderson Pk. (12)	Pearblossom (7) Gorman (20[illegible]) Parkfield (20[illegible])		Goldstone (8)			OVRO (11)
MAY		Pres[illegible] Pt. Reyes (212) Vacaville (211)					

TABLE IIIb. (continued)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING BASE STATIONS
JUNE					N/A	N/A	
JULY	Vandenberg (9)	Vacaville (211) Gorman (207) Santa Paula (405)	Anderson Pk. (12) Parkfield (208) Pearblossom (7)	Goldstone (8) Hat Creek (14)			OVR. (11)
AUGUST		JPL (6) Deadman Lake (205)	LaJolla (2) Yuma (202)				Ft. Davis (33)
SEPTEMBER	Boulder (24)	Flagstaff (27)	Vernal (413)				
OCTOBER		Buckwater (26) Lowman (20) Ft. Sill (214)	Vernal (413) Tuscarora (21) Sioux Falls (303)				OVRO (11) Ft. Davis (33)

TABLE IIIb. (continued)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING CASE STATIONS
NOVEMBER	↓	Franklin (36)	Ironton (35)		N/A	N/A	NRAO ([illegible])
DECEMBER							

a. February 1982: NASA-1 at Pinon Flats (204)

The NASA-2 will be deployed mainly in southern California, to take advantage of NASA-1/NASA-2 baselines crossing the Elsinore, San Jacinto and San Andreas Faults. Occupation of Yuma (#202), Signal Mt. (#201) and Monument Pk. (#701) by the 4m will tie Pinon Flats to the three major blocks south of the Salton Sea. The Signal Mt. site is also a tie point for NGS ground surveys. The Monument Pk. visit brings the highly mobile VLBI system to the SLR base station as part of the system intercomparison and base station interconnection. The sites next visited, Palos Verdes (#4), Santa Paula (#405) and JPL (#6) tie Pinon Flats (#204) to regions of active tectonic interest in the Transverse Ranges and eastward. These are all remeasurements of 1981-determined baselines to Goldstone (#8) and OVRO (#11).

b. April-May 1982: NASA-1 at Anderson Pk. (#12)

Locating NASA-1 at Anderson Pk., on the west side of the San Andreas Fault, makes possible direct measurement of baselines crossing the plate boundary at a variety of locations. NASA-2 will be moved to Pearblossom (#7) and Gorman (#207) for reoccupation of those sites. Parkfield (#208) is located on the east side of the San Andreas; the baseline to Anderson Pk. (#12) is such that over time it should lengthen as a consequence of plate motion. Reoccupation of Presidio (#13) and Pt. Reyes (#212) is scheduled; the Presidio-Anderson Pk. (#13-#12) baseline should shorten with time due to plate motion. The final site in this observing run in Vacaville (#211); the baseline between here and Anderson Pk. (#12) crosses the San Andreas Fault south of the Presidio-Anderson Pk. line but should also shorten with time. These sorts of baselines will make possible study of the non-uniformity of plate motion along the boundary.

1982 VLBI HIGHLY MOBILE SITES
FEBRUARY

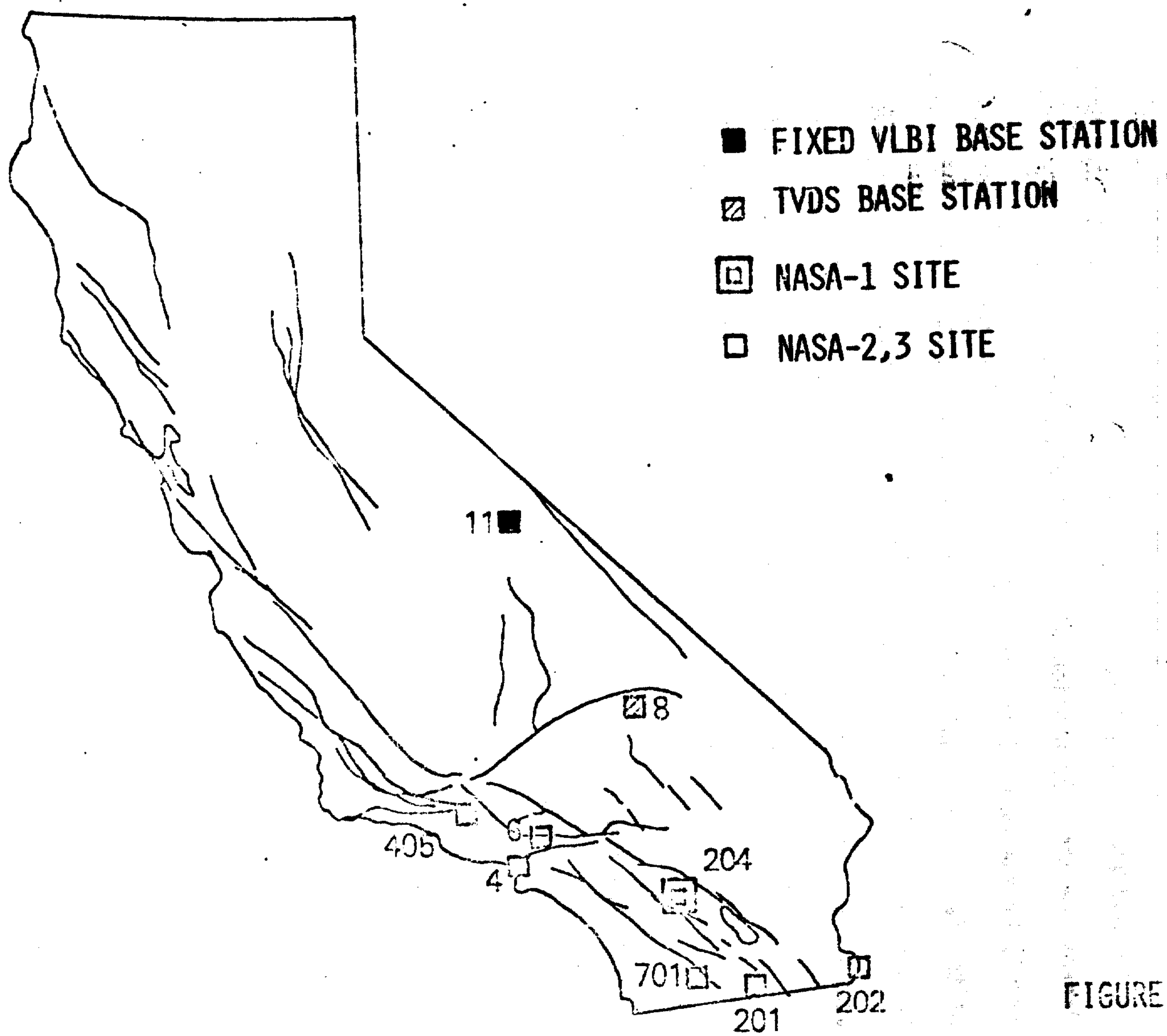


FIGURE IIIc

1982 VLBI HIGHLY MOBILE SITES
APRIL - MAY

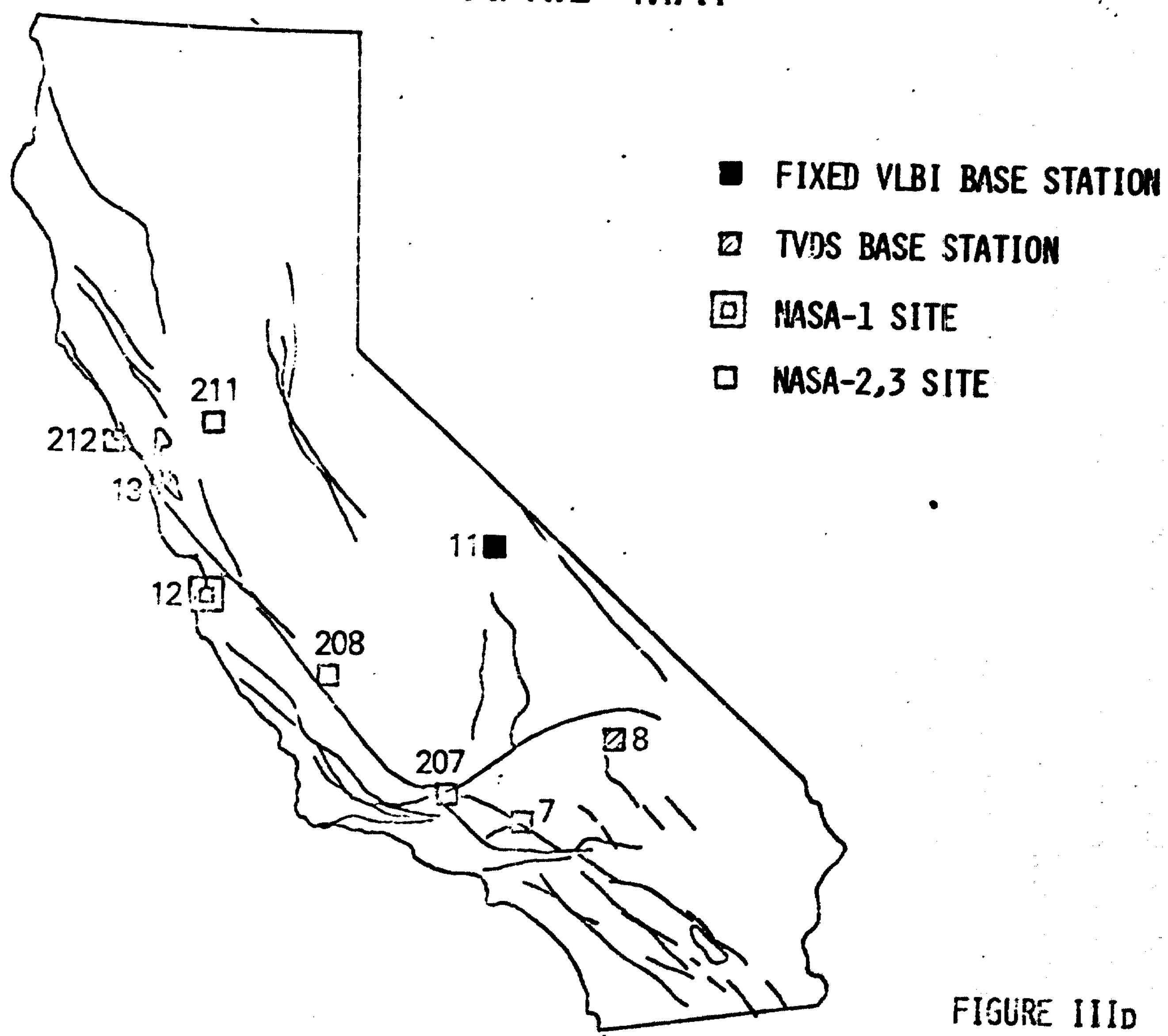


FIGURE IIID

c. July-August 1982; NASA-1 at Vandenberg (#9)

With the availability of the NASA-3 highly mobile system, site occupations have been planned as pairs, providing direct measurement of baselines not only to the 9m (and the base stations) but between the smaller systems as well. This provides a significant improvement in the ability to monitor deformation along critical baselines. As shown in Table IIIb, the paired occupations planned begin with a reoccupation of Vacaville (#211)-Anderson Pk. (#12). Not only does this repeat a measurement of an important baseline measured in May, but also ties the Vandenberg (#9) site to the Anderson Pk. (#12) site, connecting the locations of the 9m movable base station. Furthermore, the Vandenberg-Vacaville (#9-#11) baseline is one of those important San Andreas Fault-crossing measurements, where the geometry is good for measuring plate motion. The Gorman (#207)-Parkfield (#208) are visited next, determining a baseline which to a degree measures the deformation along the eastern edge of the fault.

After moving the TVDS from Goldstone (#8) to Hat Creek (#14), the NASA-1 system at Vandenberg (#9) will be making repeated observations of a good plate motion baseline. Like the line to Vacaville (#211) or the Monument Pk.-Quincy (#701-#14) baseline, the distance between stations should decrease with time. Moving the NASA-2/NASA-3 pair to Santa Paula (#405)-Pearblossom (#7) begins monitoring of E-W lines through the Transverse Ranges. JPL (#6)-La Jolla (#2) are both remeasurements of previously determined lines to OVRO (#11) but also provide, in the case of JPL-Vandenberg (#6-#9) a chance to determine E-W deformation or motion of the Pasadena site. The La Jolla-Hat Creek (#2-#14) line is similar to Monument Pk.-Quincy (#701-#14) and provides an independent measurement of this motion. La Jolla-Vandenberg (#2-#9) will help determine the stability of the Pacific plate close to but west of the nominal plate boundary.

1982 VLBI HIGHLY MOBILE SITES

JULY - AUGUST

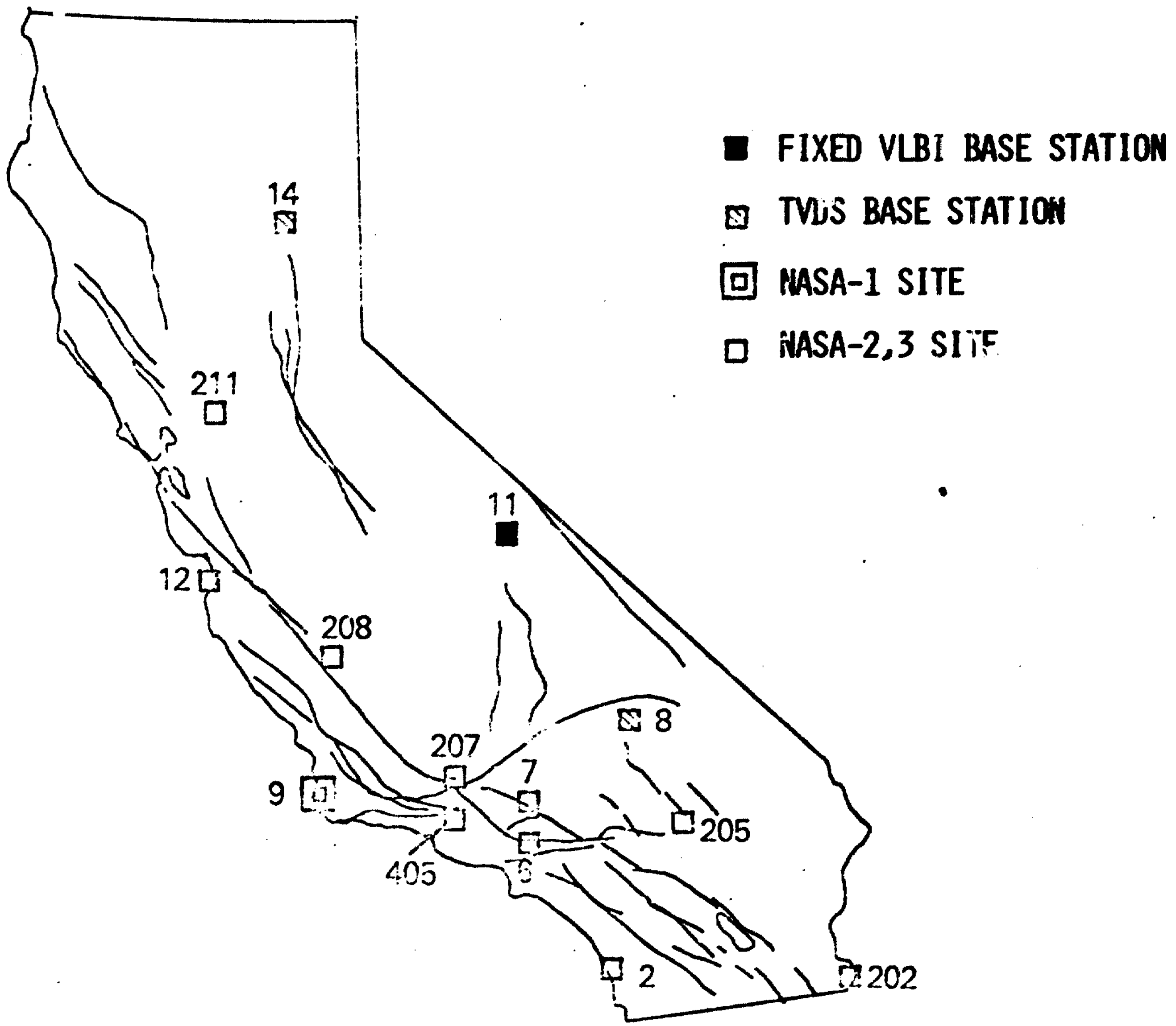


FIGURE IIIe

The final paired occupation in this run is Deadman Lake-Yuma (#205-#202) which provides a measure at the stability of southern California east of the Salton Trough, and also provides a long baseline across the entire complex of faults that make up the plate boundary between Vandenberg and Yuma (#9-#202).

d. September-November 1982: NASA-1 at Boulder (#24)

A swing through the western United States and into the central plains constitutes the final observing program for the highly mobile VLBI systems in 1982. With the TVDS located at Hat Creek (#14) and NASA-1 at Boulder (#24), baselines between these stations and OVRO (#11) and Ft. Davis (#33) comprise a basic network of measurements across the western United States. The Basin and Range is crossed with a variety of geometries. The paired occupations by the NASA-2 and NASA-3 have been selected in part to fill in the coarse network with shorter range baselines to better discriminate whatever motions may be occurring.

Locating at Flagstaff-Vernal (#27-#413) provides intermediate points along the long baseline between base stations, as well as a first order check on the stability of the Colorado Plateau. With NASA-3 remaining at Vernal (#413), the NASA-2 moves to Duckwater/Ely (#26) to provide short segment baselines across the Basin and Range between Hat Creek (#14) and Boulder (#24). Both systems will then move to Lowman-Tuscarora (#20-#21) where the directly determined baseline across the Snake River Plain will be measured for possible extension of this failed rift.

1982 VLBI HIGHLY MOBILE SITES

SEPTEMBER - NOVEMBER

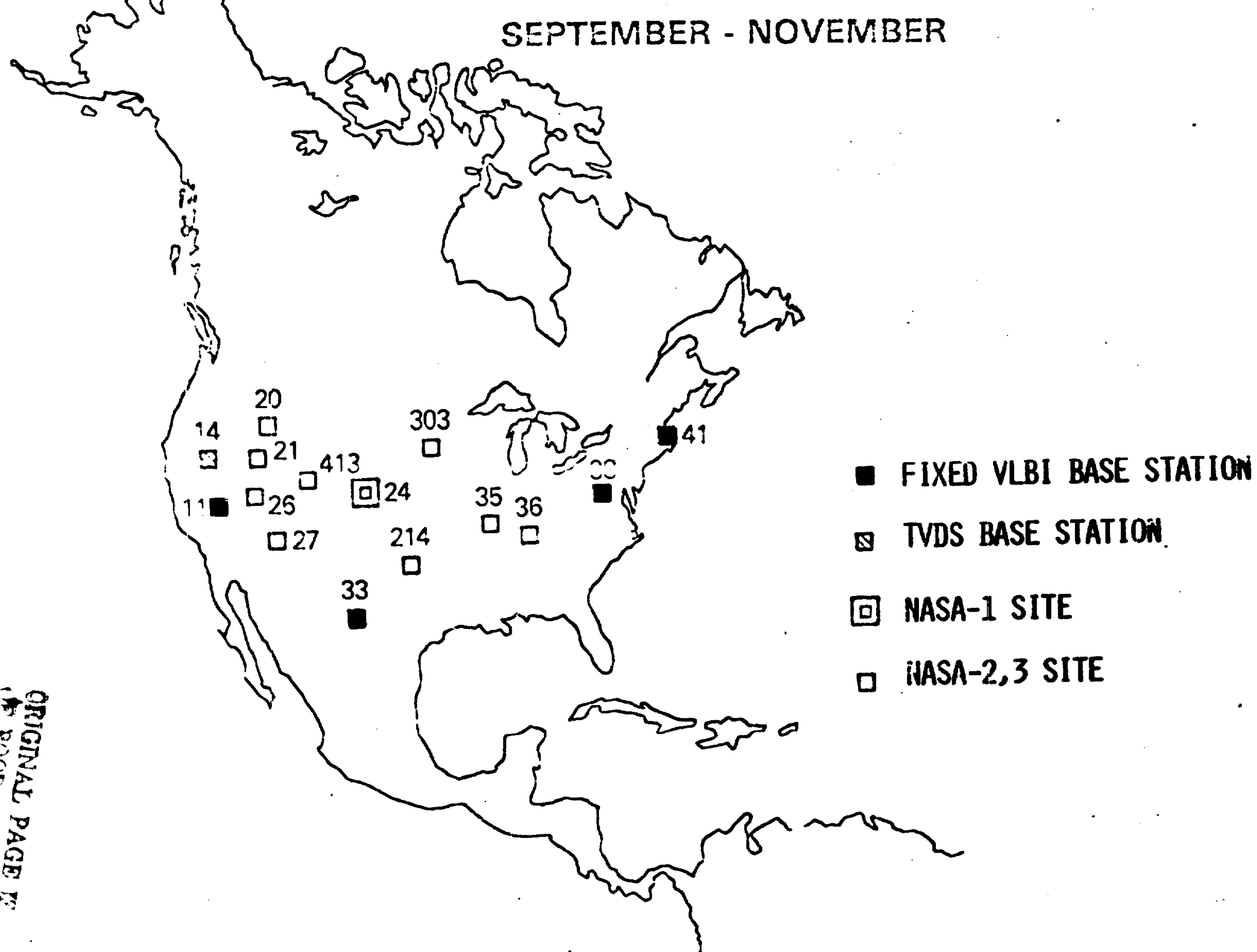


FIGURE III-F

Finally the two systems will be moved to the central portion of the North American plate to aid in studying intra-plate rigidity. From Ft. Sill (#214) and Sioux Falls (#303), baselines from Boulder (#24) and Ft. Davis (#33) measure the very center of the plate interior. Connections eastward are to the VLBI base stations at Haystack (#41) and NRAO (#38). The paired sites of Ironton (#35) and Franklin (#36) will provide a first epoch measurement across the seismically active New Madrid region.

V. THE 1983 OBSERVING PROGRAM

No new SLR systems are available in 1983 (Table I), but it will be possible to use the TLRS-2 in combination with TLRS-1 for approximately six-months out of the year. Thus the highly mobile SLR systems can be scheduled for paired occupations much like the NASA-2 and NASA-3 VLBI systems were in the second half of 1982. As described below, this means an increase in the number of sites occupied from 12 in 1982 to 16 in 1983. The highly mobile VLBI program will have two systems (NASA-2 and 3) for an entire year, and two additional TVDS packages will also be available. The increased observing capability these new systems allow lead to an expansion of the VLBI observing program into two new areas, Alaska and the Caribbean. Observations in Alaska must be made during the summer time, and the schedule described below reflects this strong constraint. The California site visits will all be completed by the end of June; sites in the western and central United States will be visited between Alaskan and Caribbean programs.

Table IVa shows the 1983 SLR observing program; the VLBI schedule is found in Table IVb.

SLR (TLRS-1, 2)

Paired occupations by the TLRS-1 and 2 of Goldstone-OVRO (#8-#11) and Vandenberg-Yuma (#9-#202) will measure interesting baselines directly in February and March. The first visits determine with laser ranging the baseline between VLBI base stations, providing an intercomparison of systems. The Vandenberg-Yuma (#9-#202) line was also measured by VLBI systems in August 1982, and provides direct information on the complicated tectonics where the San Andreas Fault splits southern California into separate blocks.

TABLE IVa. 1983 HIGHLY MOBILE SLR OBSERVING PROGRAM
(See Figures 4a,b)

	TLRS-1	TLRS-2	TLRS-3	TLRS-4	SUPPORTING BASE STATIONS
JANUARY			N/A	N/A	
FEBRUARY	Goldstone (8)	OVRO (11)			Monument Pk. (701)* Quincy (14)* Boulder (24)*
MARCH	Vandenberg (9)	Yuma (202)			Ft. Davis (33)
APRIL	San Felipe (219)	Guaymas (220)			Monument Pk. (701)* Ft. Davis (33) Mazatlan (71)*
MAY	Santa Rosalia (218)	Easter Is. (96)			
JUNE	La Paz (70)				
JULY					

NOTE: * = MOBLAS

TABLE IVa. (continued)

	TLRS-1	TLRS-2	TLRS-3	TLRS-4	SUPPORTING BASE STATIONS
AUGUST	Talara (340)		N/A	N/A	
SEPTEMBER	Antofagasto (347)				Hawaii (90)
					Easter Is. (96) Arequippa (98)*
OCTOBER	Santiago (99)				
NOVEMBER	Trinidad (31)	Gallup (30)			Monument Pk. (701)* Quincy (14)*
DECEMBER	Vernal (413)	Flagstaff (27)			Boulder (24)* Ft. Davis (33)

Paired occupations in Baja California and western Mexico will directly measure the transform motion occurring in the Gulf of California. San Felipe-Guaymas (#219-#220) are scheduled in 1983, after which the TLRS-2 is dispatched to Easter Island (#96) to continue the measurements begun in 1982. The TLRS-1 makes additional occupations in Baja California at Santa Rosalia (#218) and La Paz (#70). These Mexican observations require the Mazatlan (#71) SLR base station, as described before, and provide good baseline geometry across the Gulf of California.

The TLRS-1 will then be air-shipped to South America, visiting in turn the Talara (#340), Antofagasto (#347) and Santiago (#99) sites. Of these, Talara and Santiago represent reoccupations. Baselines between these sites and Easter Island provide good coverage of the plate convergence occurring in this part of the globe.

In November and December of 1983 both the TLRS-1 and TLRS-2 will return to the United States for paired occupations of Trinidad-Gallup (#31-#30) and Flagstaff-Vernal (#27-#413). The first pair of sites yields a baseline across the Rio Grande Rift. The second pair measures the stability of the Colorado Plateau both internally and with respect to the Boulder (#24) and Ft. Davis (#33) base stations. Ties from Flagstaff and Vernal to Quincy (#14) and Monument Pk. (#701) contribute to the measurements crossing the Basin and Range.

1983 SLR HIGHLY MOBILE SITES

FEBRUARY - JUNE, NOVEMBER - DECEMBER

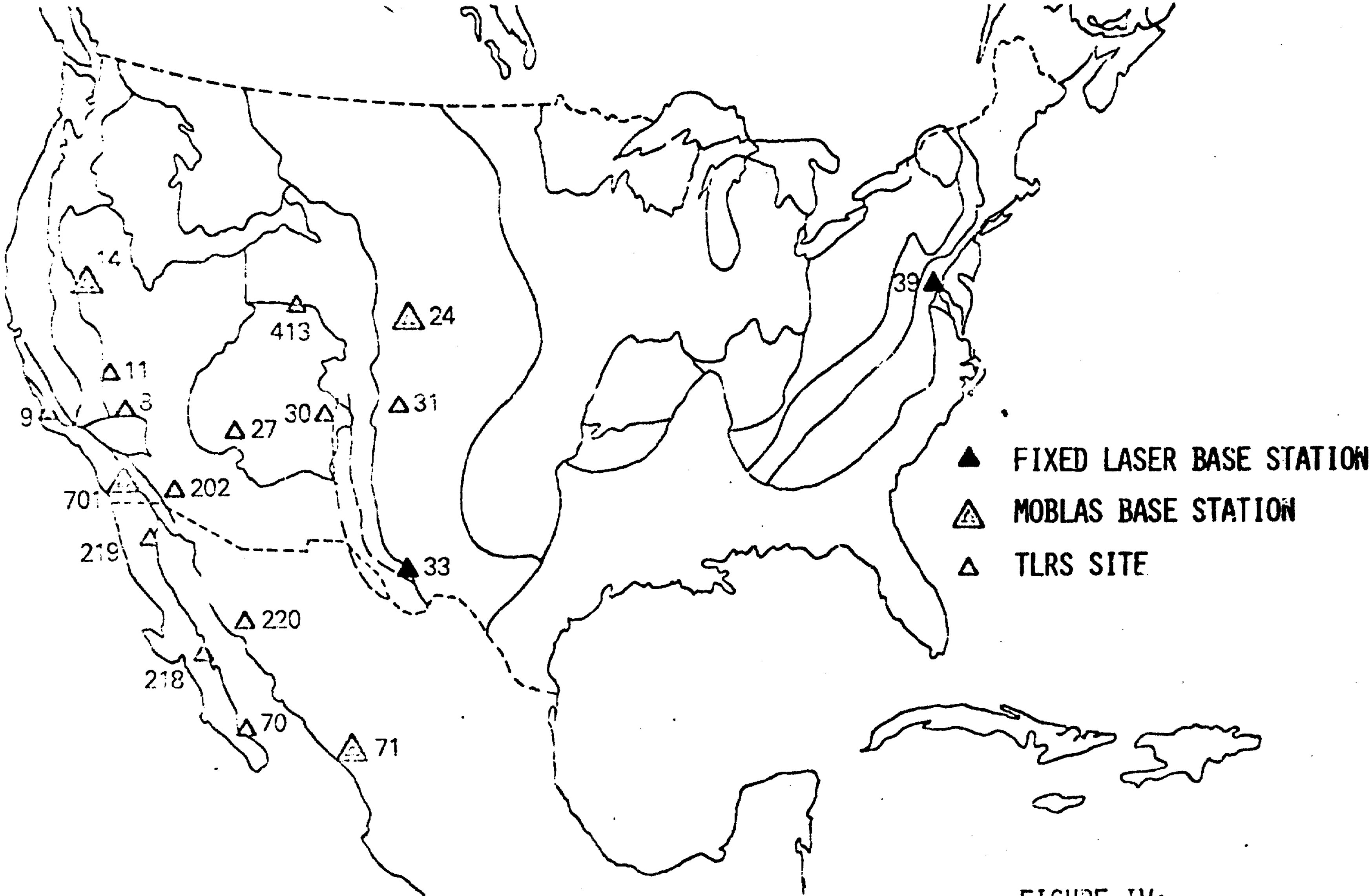
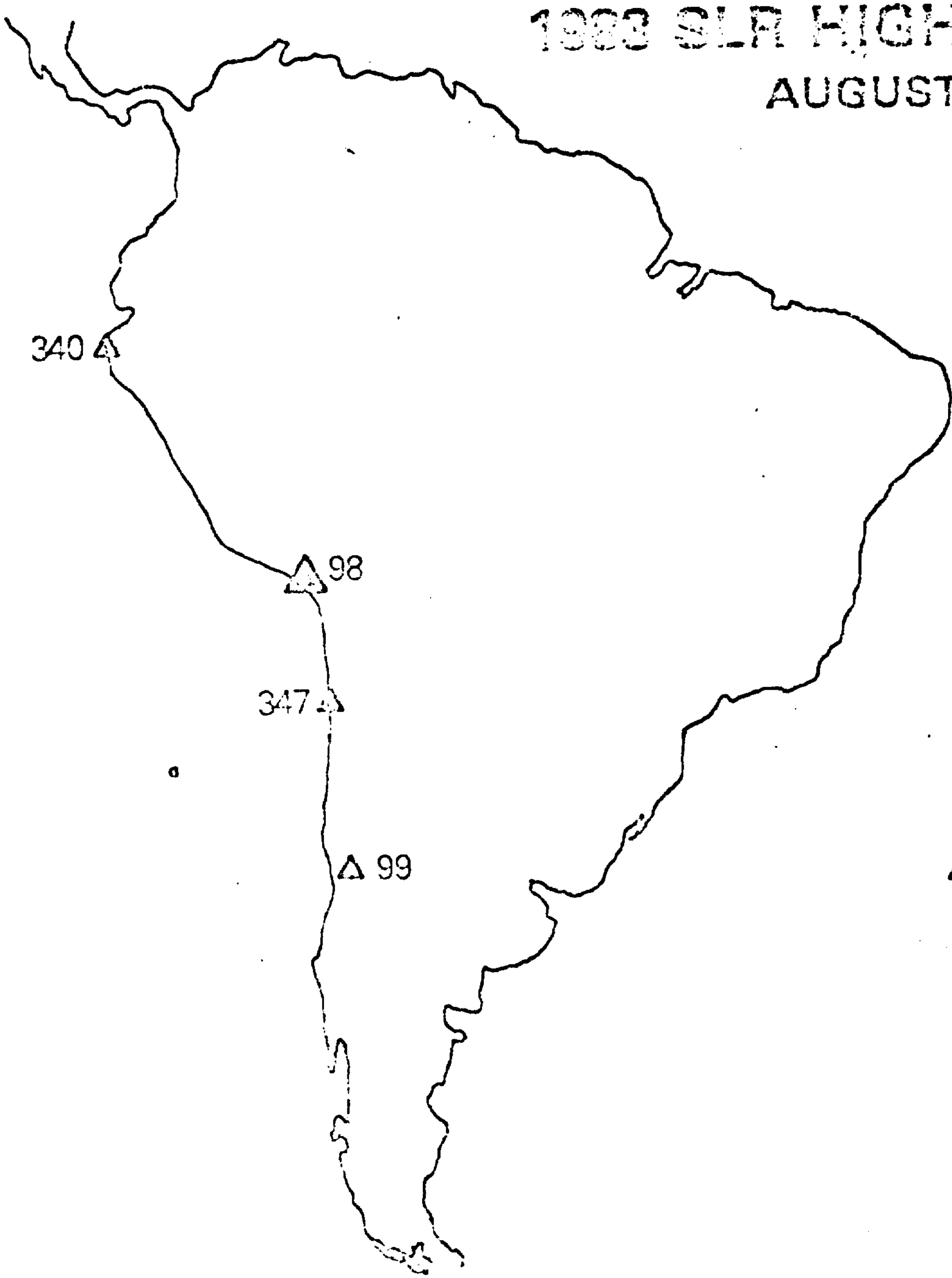


FIGURE IVA

1983 SLR HIGHLY MOBILE SITES

AUGUST - OCTOBER



△ MOBLAS BASE STATION

△ TLRS SITE

FIGURE IVB

VLBI (NASA-1, 2, 3; TVDS-1-3)

In order to accommodate the Alaskan and Caribbean observing tours planned for 1983, the highly mobile systems must complete the California observations by the middle of June. A base station in Alaska is made possible by sending a TVDS package to the Fairbanks (#61) antenna. At the same time it is desirable to have a TVDS in Hawaii (#90) to make plate motion measurements between the Pacific and Alaska.

Two Canadian observatories, Penticton (#69) and Algonquin (#67) and one United States radio observatory at Danville (#37) will also be occupied by TVDS packages during the highly mobile system occupation of central North American sites, in order to support the intra-plate deformation measurements.

The Caribbean program also requires base station support for the highly mobile systems. The fixed station at Richmond (#43) and TVDS-augmented facilities at Areceibo (#77) and Quito (#94) provide the necessary sites.

a. February 1983: NASA-1 at Pinon Flats (#204)

Paired observations by the NASA-2/NASA-3 systems are scheduled for Yuma-Monument Pk. (#202-#701), Signal Mt.-Laguna Beach (#201-#203), Palos Verdes-Santa Paula (#4-#405) and JPL-Pearblossom (#6-#7). All of these provide baselines designed to delineate the crustal deformation in southern California, through the Salton Trough north to the Transverse Ranges. Only Laguna Beach was not visited in 1982; this, in addition to providing good geometric baselines to Pinon Flats and Signal Mt., ties together NGS ground survey lines.

TABLE IVb. 1983 HIGHLY MOBILE VLBI OBSERVING PROGRAM
(See Figures 4c-f)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING BASE STATIONS
JANUARY				San Paulo (12)	Quito (94)	Santiago (99)	*=Dedicated Base Station
FEBRUARY	Pinyon Flats (204)	Yuma (202) Signal Mt. (201) Palos Verdes (4) JPL (6)	Monument Pk. (701) Laguna Beach (203) Santa Paula (405) Pearblossom (7)				OVRO (11) Ft. Davis (33) Goldstone (6)*
MARCH							
APRIL	Anderson Pk. (12)	Pearblossom (7) Vandenberg (9) Parkfield (208) Presidio (13)	Gorman (207) Vacaville (211) Pt. Reyes (212) Pt. Reyes (212)				OVRO (11) Goldstone (6)*
MAY	Vandenberg (9)	Gorman (207)	Parkfield (208)	Kwajalein (136)	Hawaii (90)	Fairbanks (61)	

TABLE IVb. (continued)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING BASE STATIONS
JUNE		Santa Paula (405) JPL (6) Deadman Lake (205)	Pearblossom (7) La Jolla (2) Yuma (202)				OVRO (11) Ft. Davis (33) Goldstone (8)*
JULY		Fairwell (62) Wiseman (60)	Yakatat (310) Seward (64)	Penticton (69)			
AUGUST	Boulder (24)	Dillingham (63)	Cordova (65)				
SEPTEMBER		Lowman (20) Duckwater (26) Flagstaff (27)	Tuscarora (21) Vernal (413) Vernal (413)		Algonquin (67)	Danville (37)	OVRO (11) Ft. Davis (33) Hat Creek (14)*
OCTOBER		Ft. Sill (214) Franklin (36)	Sioux Falls (303) Ironton (35)				Haystack (41) NRAO (38) Richmond (43)

TABLE IVb. (continued)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING BASE STATIONS
NOVEMBER		Belmopan (74)	Barbados (502)	Arecelbo (77)	Quito (94)	Santiago (99)	Ft. Davis (33)
DECEMBER		Grand Turk (76) Jamaica (501)	Ciudad Bolivar (330) Santa Marta (322)				Richmond (43)

1983 VLBI HIGHLY MOBILE SITES

FEBRUARY

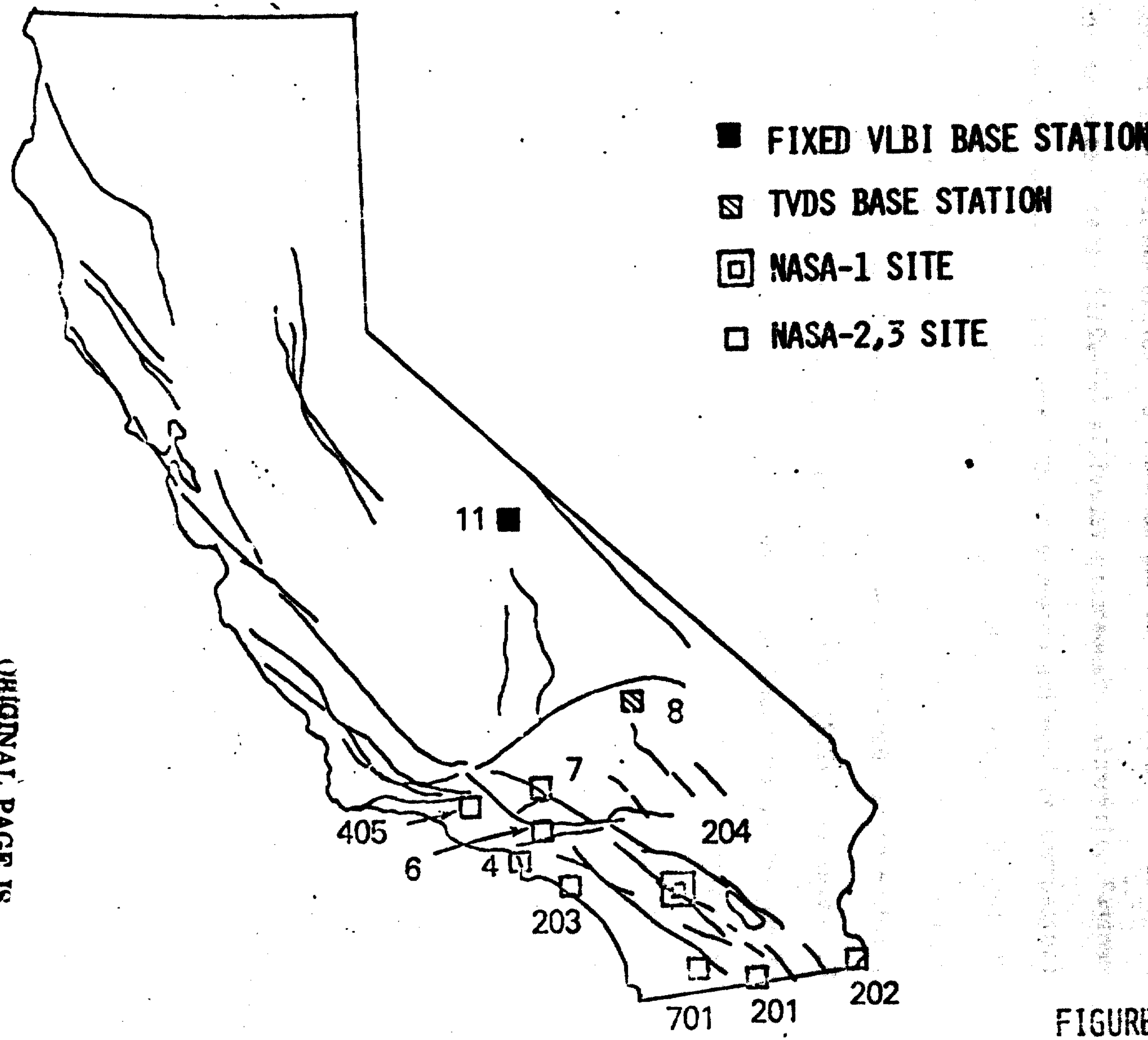


FIGURE IVc

b. <u>April 1983: NASA-1 at Anderson Pk. (#12)</u>

The sites visited in this month are those scheduled in the previous year, but paired observations by two systems means direct measurement of baselines of particular interest. The scheduled occupations begin with Pearblossom-Gorman (#7-#207) which ties the southern California measurements to those in central California. Vandenberg-Vacaville (#9-#211) remeasures a San Andreas Fault-crossing baseline observed in 1982 and also ties Vandenberg and Anderson Pk. together to monitor the stability of the Pacific Plate near the plate boundary. Simultaneous occupation of Parkfield (#208) and Pt. Reyes (#212) yields a direct baseline crossing the San Andreas Fault, as does the Presidio-Pt. Reyes (#13-#212) line measured next. Both Parkfield and Presidio are east of the Fault, and baselines to the 9m at Anderson Pk. should help define the near-margin plate motion.

c. <u>May-June 1983: NASA-1 at Vandenberg (#9)</u>

The dedicated base station system at Goldstone (#8), available for the first time in 1983, is a transportable MARK III VLBI data system similar to the TVDS. As such it can be moved to Hat Creek (#14) in support of California and western United States highly mobile system observations, as indicated in Table IVb. With the NASA-1 at Vandenberg, the NASA-2/NASA-3 combination revisit 4 of the 5 pairs of sites occupied the previous year: Gorman-Parkfield (#207-#208), Santa Paula-Pearblossom (#405-#7), JPL-La Jolla (#6-#2) and Deadman Lake-Yuma (#205-#202). This second year of observation provides first epoch <u>velocity</u> measurements along these baselines.

1983 VLBI HIGHLY MOBILE SITES
APRIL

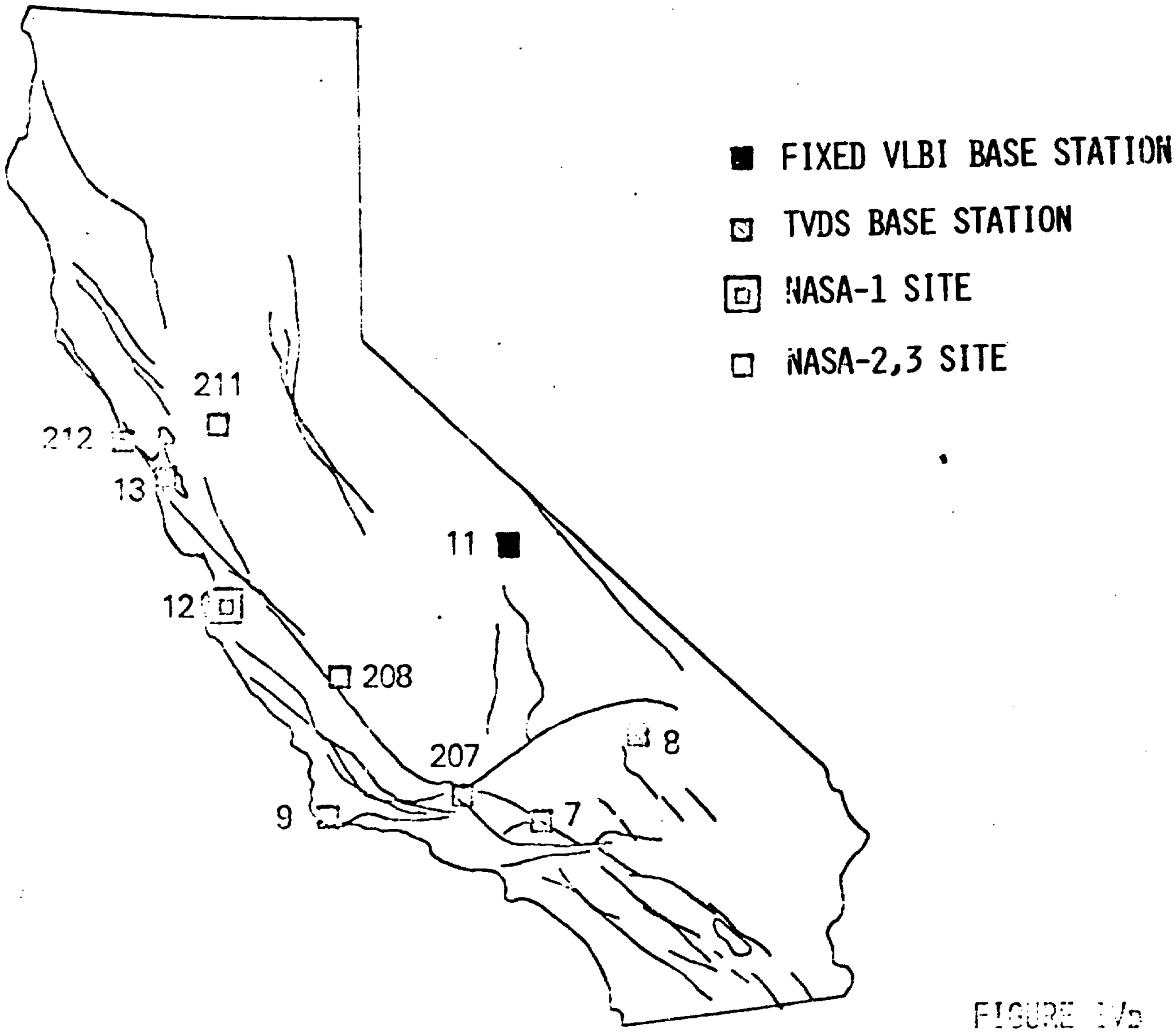


FIGURE IVb

1983 VLBI HIGHLY MOBILE SITES

MAY - JUNE

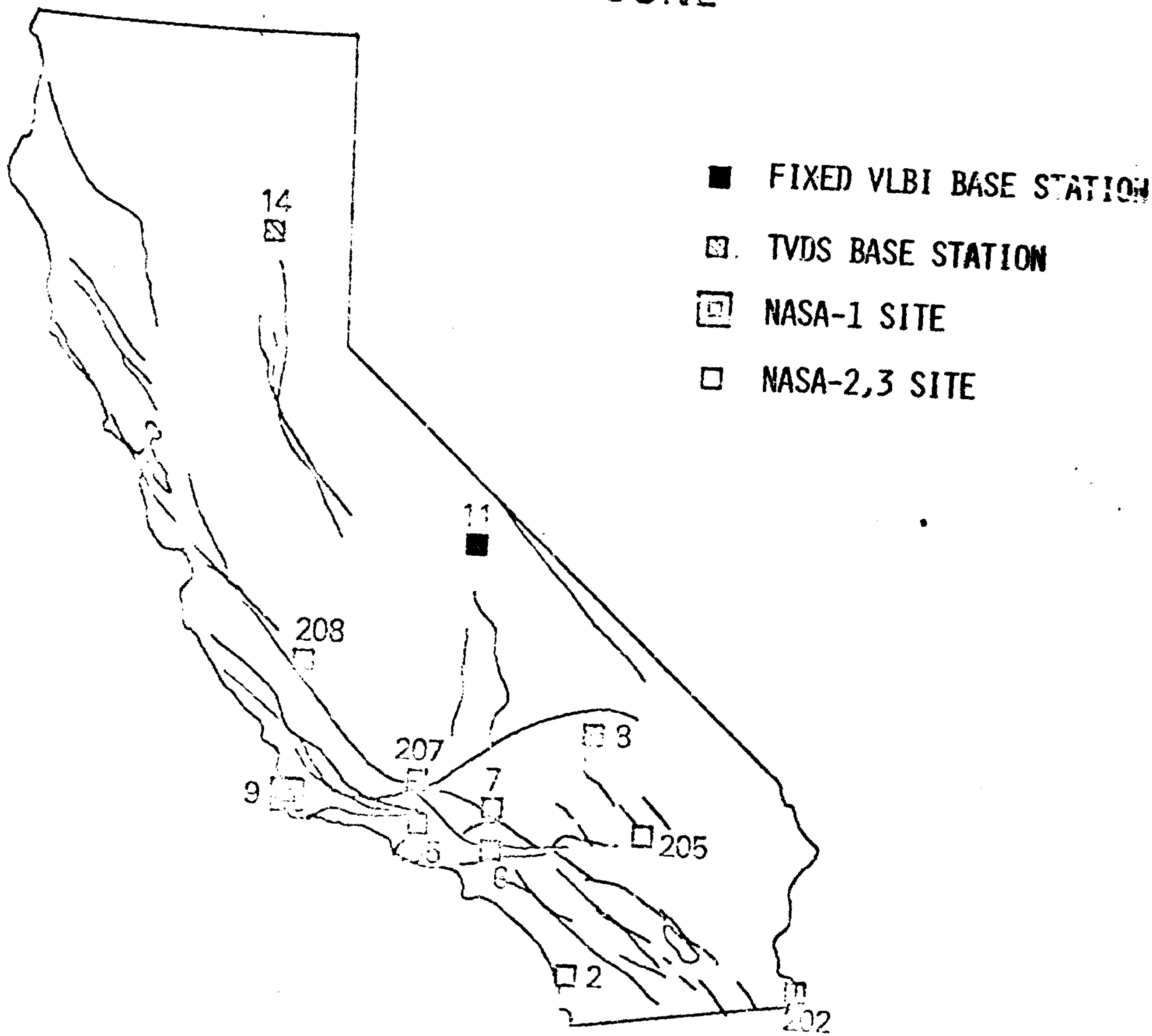


FIGURE IVE

d. July-August 1983:

These two months are devoted to paired Alaskan occupations by the NASA-2 and NASA-3, working against the TVDS-augmented antenna at Fairbanks. The difficulty in transporting even highly mobile systems in Alaska restricts the observations to ~3 pairs of sites. Present plans call for occupation of Fairwell-Yakatat (#42-#310), Wiseman-Seward (#60-#64) and Dillingham-Cordova (#63-#65), although details of the Alaska program are still under study.

e. September-October 1983: NASA-1 at Boulder (#24)

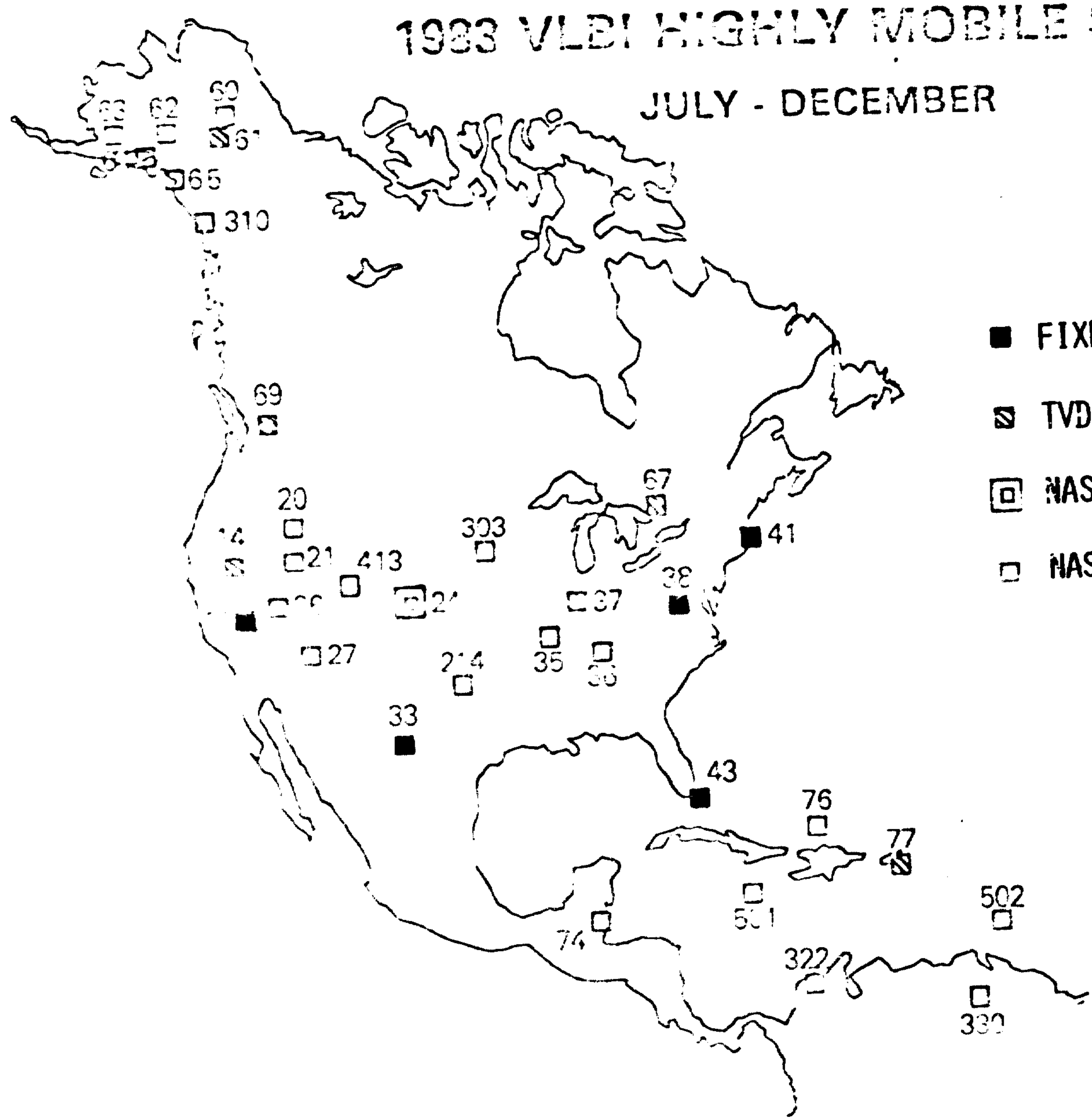
Paired occupations of western and central United States sites are the same as those for 1982, though in slightly different order (see Table IVb, compare Table IIIb): Lowman-Tuscarora (#20-#21), Duckwater-Vernal (#26-#413), Flagstaff-Vernal (#27-#413), Ft. Sill-Sioux Falls (#214-#303) and Ironton-Franklin (#35-#36). A TVDS at Danville (#37) and contributing observations at Haystack (#41), NRAO (#38) and Richmond (#43) in the east and Boulder (#24) and Ft. Davis in the west provide numerous crossing baselines throughout the plate interior. This situation is improved still further by the augmentation of the Penticton (#69) and Algonquin (#67) observatories by TVDS packages.

f. November-December 1983:

A preliminary reconnaissance of the crustal deformation in the Caribbean is planned, beginning at the end of 1983. Details are still under study, but current plans call for TVDS base stations at Areceibo (#77) and Quito (#94) to complement the fixed station at Richmond (#43). The NASA-2/NASA-3 combination would sequentially occupy Belmopan-Barbados (#74-#502), Grand Turk-Ciudad Bolivar (#76-#330) and Jamaica-Santa Marta (#501-#332). These sites are shown in Figure 4f.

1983 VLBI HIGHLY MOBILE SITES

JULY - DECEMBER



■ FIXED VLBI BASE STATION

▨ TVDS BASE STATION

⊡ NASA-1 SITE

□ NASA-2,3 SITE

FICURE IVF

VI. THE 1984 OBSERVING PROGRAM

Major changes in the availability of systems for 1984 and beyond occur only for the SLR program. Two new highly mobile systems (TLRS-3 and 4) are scheduled to begin operation in January. This significantly increases the number of sites that can be occupied but also provides much greater choice in baseline selection when two systems are used in the paired-occupation mode. This flexibility is exploited in South American measurements, as discussed below. In 1984 28 sites will be occupied by highly mobile SLR systems, compared with 16 in 1983.

The only changes in the VLBI observing program in 1984 are those allowed by previous experience. No new systems will be available, but prior occupation of remote regions (Alaska, Caribbean) is expected to reduce occupation time at each site. Six new sites have been added in the Canada/western United States area, and some rearrangement of the Caribbean program has been scheduled to improve baseline geometry. In all 56 occupations by highly mobile VLBI systems (NASA-2, NASA 3) are planned in 1984. The TVDS schedule remains unchanged from 1983, providing a mixture of highly mobile system support and plate/intra-plate motion studies.

SLR (TLRS 1-4)

The SLR observing program for 1984 is shown in Table Va and Figures 5a,b. Initially all four systems are employed together, with paired occupations of San Felipe-Guaymas (#219-#220) and Santa Rosalia-Los Mochis (#218-#221) providing good baselines across the Gulf of California. The TLRS-2 will be sent to La Paz

TABLE Va. 1984-86 HIGHLY MOBILE SLR OBSERVING PROGRAM
(See Figures 5a,b)

	TLRS-1	TLRS-2	TLRS-3	TLRS-4	SUPPORTING BASE STATIONS
JANUARY					
FEBRUARY	San Felipe (219)	Santa Rosalia (218)	Los Mochis (221)	Guaymas (220)	Monument Pk. (701)* Quincy (14)* Boulder (24)*
MARCH	Vandenberg (9)	La Paz (70)	Mt. Hopkins (28)	Yuma (202)	Ft. Davis (33) Mazatlan (71)*
APRIL	Goldstone (8)			OVRO (11)	
MAY		Easter Is. (96)	Galapagos (93)		
JUNE	Talara (340)			Loja (339)	Hawaii (90) Easter Is. (96)
JULY	Lima (3[illegible]3)			San Ramon (342)	Arequippa (98)*

NOTE: * = MOBLAS

TABLE Va. (continued)

	TLRS-1	TLRS-2	TLRS-3	TLRS-4	SUPPORTING BASE STATIONS
AUGUST	Antofagasto (347)		San Felix (97)	Salta (348)	Hawaii (90) Easter Is. (96)
SEPTEMBER	Santiago (99)			San Luis (351)	Arequippa (98)*
OCTOBER	Bear Lake (22)				Monument Pk. (701)*
NOVEMBER	Gallup (30)	✓	✓	Trinidad (31)	Quincy (14)* Boulder (24)* Ft. Davis (33)
DECEMBER	Magdalena (29)	Flagstaff (27)	Vernal (413)	Roswell (32)	

(#70) to provide an additional baseline to Mazatlan (#71) where a MOBLAS base station continues to operate. Meanwhile the TLRS-1, 2 and 3 will perform a triple occupation of Vandenberg (#9), Mt. Hopkins (#28) and Yuma (#202) to measure deformation in the southern California-southern Basin and Range area. Connecting baselines to Monument Pk. (#701) and Ft. Davis (#33) further define the motions. This triplet of sites will be simultaneously occupied in 1985 and 1986.

Two systems will go to the Nazca Plate, one to Easter Island (#96) and one to the Galapagos Islands (#93). Together they provide base station support for occupations of South American sites, but also of themselves begin a three-year monitoring of the internal deformation of the Nazca Plate.

The two systems remaining in the United States will reoccupy the Goldstone (#8) and OVRO (#11) sites where VLBI base stations exist. These systems will then be airshipped to South America and begin a series of paired occupations. The selected sites include Talara-Loja (#340-#339), Lima-San Ramon (#343-#342), Antofagasto-Salta (#347-#348) and Santiago-San Luis (#99-#351). These pairs provide short baselines to study strain accumulation and deformation associated with the convergent plate boundary. Baselines between these sites and Easter, Galapagos and San Felix (#97) will measure the convergence at many points along the coast. It is desirable to move the TLRS-3 system from the Galapagos to San Felix, if possible, both to support the southern half of the South American occupations and to provide another intra-plate baseline for Nazca plate rigidity study.

1984 SLR HIGHLY MOBILE SITES

FEBRUARY - APRIL, OCTOBER - DECEMBER

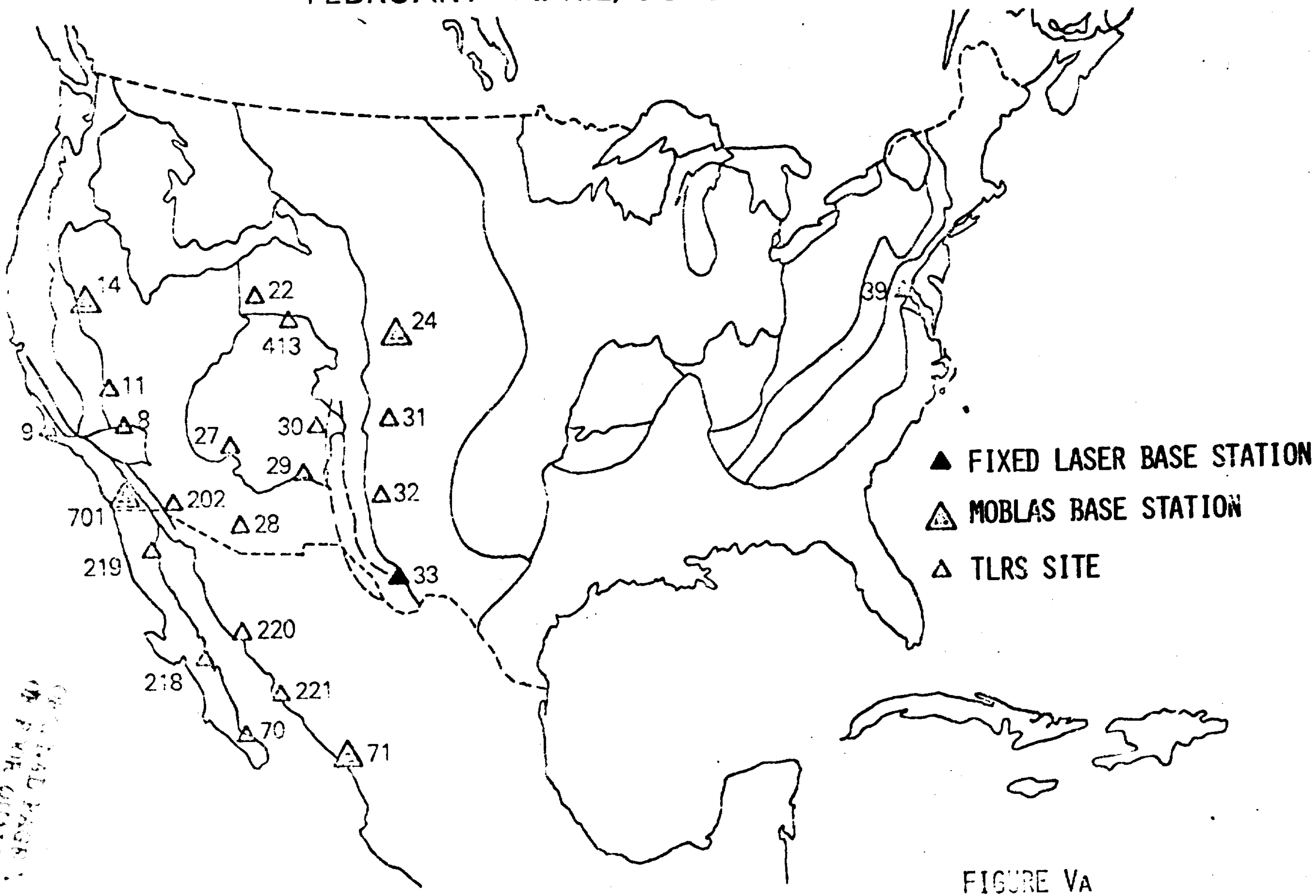
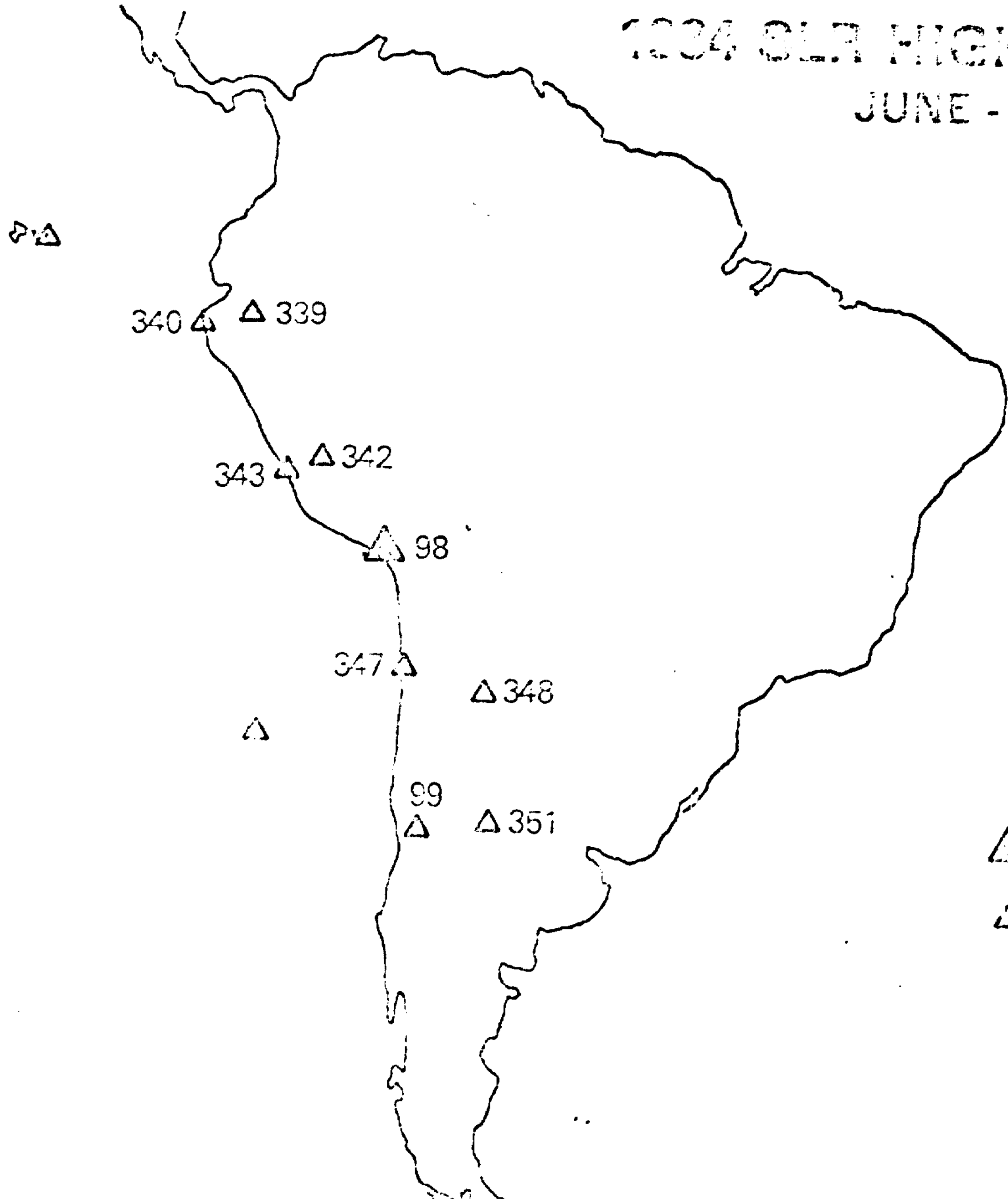


FIGURE VA

1984 SLR HIGHLY MOBILE SITES

JUNE - SEPTEMBER



MOBLAS BASE STATION

TLRS SITE

FIGURE V3

If possible a reoccupation of Bear Lake (#22) by the TLRS would be desirable following the South American observations. Two systems are due to occupy Gallup-Trinidad (#30-#31) in November in order to remeasure the baseline across the Rio Grande Rift. The next month an additional baseline across the rift is determined by the paired occupation of Magdalena-Roswell (#29-#32). Flagstaff-Vernal (#27-#413) are to be visited simultaneously by the other two highly mobile SLR systems.

VLBI (NASA-1, 2, 3; TVDS 1-3)

The 1984 highly mobile VLBI program is very similar to the 1983 program, as comparison of Tables Vb and IVb indicates. Only the modifications are emphasized below:

a. February 1984: NASA-1 at Pinon Flats (#204)

This schedule is identical to the 1983 program for February (Figure 4c).

b. April, 1984: NASA-1 at Anderson Pk. (#12)

This schedule is identical to the 1983 program for April (Figure 4d).

c. May-June 1984: NASA-1 at Vandenberg (#9)

This schedule is identical to the 1983 program for May-June (Figure 4e).

d. July-August 1984:

Following the paired reoccupations of Fairwell-Yakatat (#62-#310), Wiseman-Seward (#60-#64) and Dillingham-Cordova (#63-#65) the NASA-2 and NASA-3 will occupy Yellowknife (#408) and Churchill (#66) to provide plate interior points for baselines from Fairbanks (#61), Penticton (#69), Haystack (#41), NRAO (#38), Ft. Davis (#33) and Boulder (#24).

TABLE Vb. 1984 HIGHLY MOBILE VLBI OBSERVING PROGRAM
See Figures 4c-e, 5c)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING BASE STATIONS
JANUARY				Sao Paulo (102)	Quito (94)	Santiago (99)	* = Dedicated Base Station System
FEBRUARY	Pinyon Flats (204)	Yuma (202) Signal Mt. (201) Palos Verdes (4) JPL (6)	Monument Pk. (701 Laguna Beach (203) Santa Paula (405) Pearblossom (7)				OVRO (11) Ft. Davis (33) Goldstone (2)*
MARCH							
APRIL	Anderson Pk (12)	Pearblossom (7) Vandenberg (9) Parkfield (208) Presidio (13)	Gorman (207) Vacaville (211) Pt. Reyes (212) Pt. Reyes (212)				OVRO (11) Goldstone (8)*
MAY	Vandenberg (9)	Gorman (207)	Parkfield (208)	Kwajalein (136)	Hawaii (90)	Fairbanks (61)	

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TABLE Vb. (continued)

	NASA-1	NASA-2	NASA-3	TVOS 1	TVOS 2	TVOS 3	SUPPORTING BASE STATIONS
JUNE		Santa Paula (405) JPL (6) Deadman Lake (205)	Pearblossom (7) La Jolla (2) Yuma (202)				OVRO (11) Ft. Davis (33) Goldstone (8)*
JULY		Fairwell (62) Wiseman (60)	Yakatat (210) Seward (64)	Penticton (69)			
AUGUST	Boulder (24)	Billingham (63) Yellowknife (408)	Cordova (65) Churchill (65)				
[illegible]		S[illegible]y (19) [illegible] (20) Fallon (411) [illegible] Water (26) Flagstaff (27)	Yellowstone (302) Tuscarora (21) Delta (412) Vernal (413) Vernal (413)		Algonquin (67)	Danville (37)	OVRO (11) Ft. Davis (33) Hat Creek (14)* Haystack (41) [illegible] (30)
[illegible]		Ft. Sill (214) Franklin (36)	Sioux Falls (303) Ironton (35)				Richmond (43)

TABLE Vb. (continued)

	NASA-1	NASA-2	NASA-3	TVDS 1	TVDS 2	TVDS 3	SUPPORTING BASE STATIONS
NOVEMBER				Areceibo (77)	Quito (94)	Santiago (99)	
		Belmopan (74)	Barbados (502)				
		Santa Marta (322)	Barbados (502)				Ft. Davis (30)
		Santa Marta (322)	Ciudad Bolivar (330)				
DECEMBER		Grand Turk (76)	Ciudad Bolivar (330)				Richmond (43)
		Grand Turk (76)	Jamaica (501)				

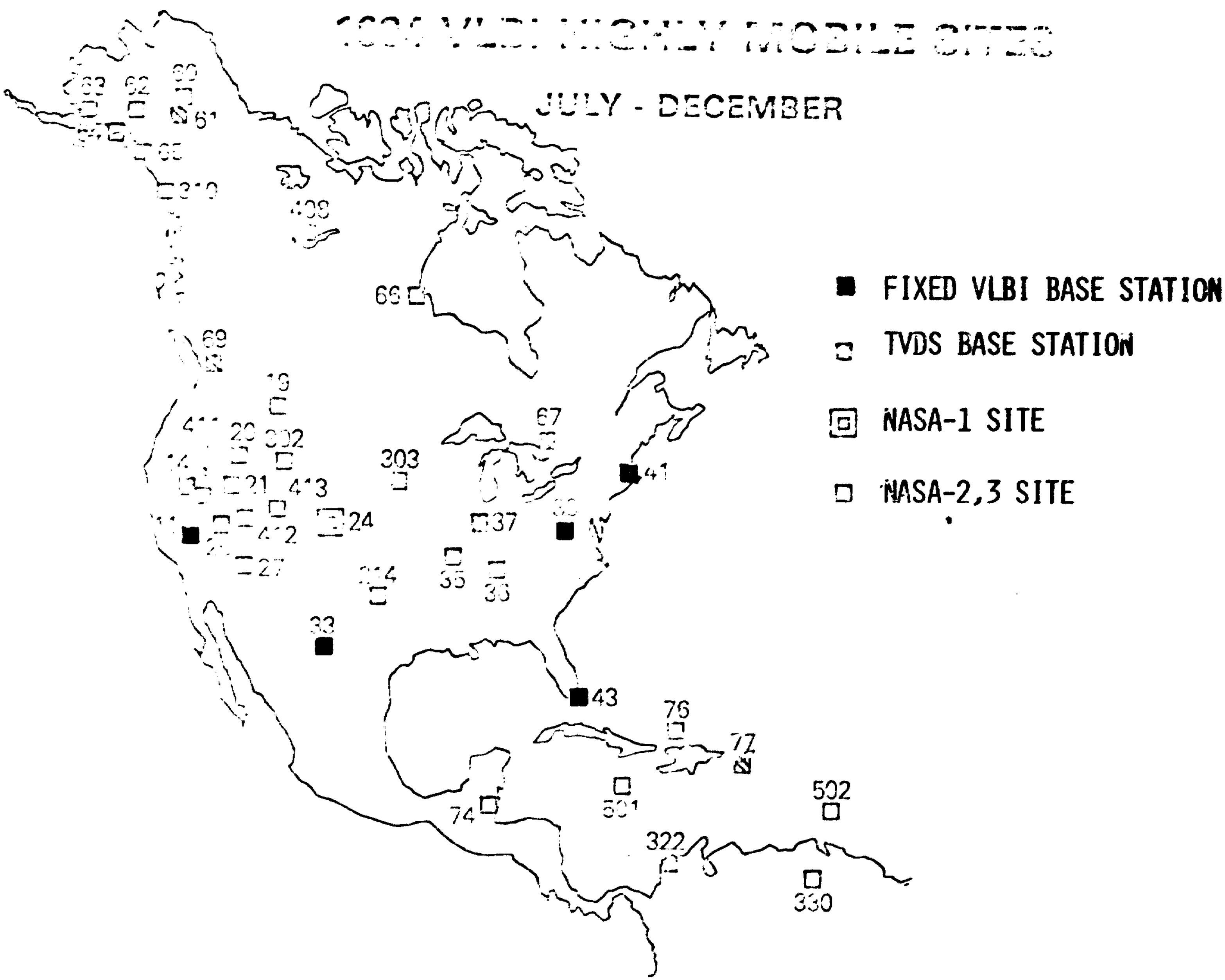
VLBI HIGHLY MOBILE SITES
JULY - DECEMBER
FIXED VLBI BASE STATION
TVDS BASE STATION
NASA-1 SITE
NASA-2,3 SITE
63
62
61
310
408
66
69
19
20
302
303
67
41
21
24
37
33
27
35
36
43
76
77
74
502
322
330

FIGURE Vc

e. September-October 1984: NASA-1 at Boulder (#24)

The western United States observations will begin with a new pair of sites, at Shelby (#19) and Yellowstone (#302). Shelby is added to extend the measurements northward to the plate interior and Yellowstone is a site of expected vertical motions. The remaining paired occupations are similar to the 1983 schedule with one modification. Two new sites, Fallon-Delta (#411-#412) have been inserted to provide shorter baselines within the Basin and Range.

f. November-December 1984:

The sites to be visited in the Caribbean are the same as in 1983, but the deployment has been slightly modified to provide more baselines crossing the region. The Belmopan-Barbados (#74-#502) visit will be followed by Santa Marta-Barbados (#322-#502), so that only one system will be moved between observing sessions. Likewise, the next-scheduled pair is Santa Marta-Ciudad Bolivar (#322-#330), then Grand Turk-Ciudad Bolivar (#76-#330) and finally Grand Turk-Jamaica (#76-#501). These baselines should help define the gross motions and deformation of the Caribbean plate and provide a basis for future detailed studies of the complex area.

VII. THE 1985, 1986 OBSERVING PROGRAM

Because no new systems are available to the Project after 1984, and because a minimum 3-year time base of observations is desired, the 1985 and 1986 highly mobile observing programs are scheduled to be carbon copies of the 1984 program (Table Va, Vb; Figures 5a-c). This is in keeping with the basic constraints outlined earlier. In reality it is likely that changes will occur throughout the Project as new information and results change the criteria under which this program has been set up. The program outlined here, and expected for the 1985-86 period, is tentative. It does, however, meet the goals and scientific directives of the Crustal Dynamics Project for which the highly mobile VLBI and SLR systems are required.

VIII. SUMMARY

The highly mobile observing program described above results in an increase over time in the number of sites visited and the number of baselines measured. In 1981 the SLR highly mobile system (TLRS-1) will occupy eight sites. This number grows to 28 in 1984-1986 as new systems become available. Likewise, the VLBI highly mobile systems will make 56 occupations of 43 different sites in 1984, a significant increase over the 19 occupations of 17 different sites scheduled for 1981.

Table VI shows how the site occupations are distributed geographically each year for the two types of observing systems. The dominant effort of the highly mobile systems (TLRS-1-4; NASA 2, 3) is clearly in the California-western United States area. In 1981 all the observations are in this region; in 1984-1986, 46 out of 84 total site occupations are in the California-western United States area. The remaining 38 are distributed over five regions from Alaska to South America.

TABLE VI. SITE OCCUPATIONS BY HIGHLY MOBILE SLR, VLBI SYSTEMS: 1981-86

(TLRS 1-4; NASA 2, 3)

	81			82			83			84		
	SLR	VLBI	TOT	SLR	VLBI	TOT	SLR	VLBI	TOT	SLR	VLBI	TOT
CALIFORNIA	4	15	19	4	22	26	4	24	28	4	24	28
WESTERN UNITED STATES	4	4	8	3	6	9	4	6	10	8	10	18
MEXICO	-	-	-	2	-	2	4	-	4	5	-	5
CENTRAL UNITED STATES	-	-	-	-	4	4	-	4	4	-	4	4
ALASKA, CANADA	-	-	-	-	-	-	-	6	6	-	8	8
CARIBBEAN	-	-	-	-	-	-	-	6	6	-	10	10
SOUTH AMERICA, NAZCA	-	-	-	3	-	3	4	-	4	11	-	11
	8	19	27	12	32	44	16	46	62	28	56	84

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REFERENCES

Allenby, R.J., Implications of very long baseline interferometry measurements on North American intra-plate crustal deformation, Tectonophysics, in press.

Atwater, T., Implications of plate tectonics for the Cenozoic tectonic evolution of western North America, Geol. Soc. Amer. Bull., 81, 3513-3535, 1970.

Frey, H.V., R.J. Allenby and P.D. Lowman, New satellite laser ranging and very long baseline interferometry sites for crustal dynamics, in preparation, 1980

Meade, B.K., Report on the sub-commission of recent crustal movements in North America. Presentation to XV General Assembly of I.U.G.G., Moscow, 1971.

Savage, J.C. and R.O. Burford, Geodetic determination of relative plate motion in central California, J. Geophys. Res., 78, 5771-5787, 1977.

Savage, J.C., W.H. Prescott, M. Lisowski and N. King, Deformation across the Salton Trough, California, 1973 1977, J. Geophys. Res., 84, 3069-3079, 1979.

Smith, D.C., R. Kolenkiewicz, P.J. Dunn and M.H. Torrence, The measurement of fault motion by satellite laser ranging, Tectonophysics, 52, 59-67, 1979.

Stewart, J.H., Basin and Range structure: A system of horsts and grabens produced by deep-seated extension, Geol. Soc. Amer. Bull., 82, 1019-1044, 1971.